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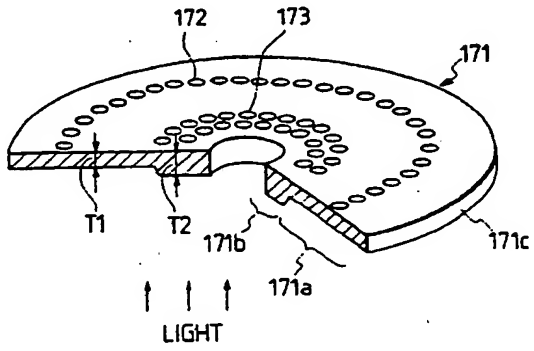
(54) Optical disk

(57) An optical disk, comprising:

an information recording substrate (171) having a first region (171a) having a first thickness (T1), and a plurality of first recording pits (172) placed at the first region of the information recording substrate for recording pieces of recording information at a first recording density; characterised in that the information recording substrate also has a second region (171b) having a second thickness (T2) larger than the first thickness (T1);
and by a plurality of second recording pits (173) placed at the second region of the information recording substrate for recording distinguishing information at a second recording density which is lower than the first recording density, the distinguishing information indicating that the first region of the information recording substrate has the first thickness (T1).

FIG. 53



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Description

The present invention relates to an optical disk in which a series of high density recording pits and a series of comparatively low density recording pits are provided.

An optical memory technique has been put to practical use to manufacture an optical disk in which a pit pattern formed of a series of pits is drawn to record information. The optical disk is utilized as a high density and large capacity of information medium. For example, the optical disk is utilized for a digital audio disk, a video disk, a document file disk, and a data file disk. To record information on the optical disk and to reproduce the information from the optical disk, a light beam radiated from a light source is minutely converged in an imaging optical system, and the light beam minutely converged is radiated to the optical disk through the imaging optical system. Therefore, the light beam is required to be reliably controlled in the imaging optical system with high accuracy.

Fig. 1 is a constitutional view of a conventional optical head apparatus proposed in Japanese Patent Application No. 46630 of 1991 which is applied by inventors of the present invention.

As shown in Fig. 1, a conventional optical head apparatus 11 for recording or reproducing information on or from an information medium 12 such as an optical disk is provided with a light beam source 13 such as a semiconductor laser, a transmission type of blazed hologram 14 for transmitting a light beam L1 radiated from the light beam source 12 without any diffraction in an outgoing optical path and diffracting a light beam L2 reflected on the information medium 12 in a returning optical path, an objective lens 15 for converging the light beam L1 transmitting through the hologram 13 on the information medium 14 to read the information, an actuator 16 for integrally moving the objective lens 15 with the blazed hologram 13 to focus the light beam L1 on the information medium 12 with the objective lens 15, and a photo detector 17 for detecting the intensity of the light beam L2 reflected on the information medium 12 to reproduce the information.

As shown in Fig. 2A, a relative position between the blazed hologram 14 and the objective lens 15 is fixed by a fixing means 18. Or, as shown in Fig. 2B, a blazed pattern is formed on a side of the objective lens 15 to integrally form the blazed hologram 14 with the objective lens 15.

An optical disk having a high density memory capacity has been recently developed because of the improvement in a design technique of an optical system and the shortening of the wavelength of light radiated from a semiconductor laser. For example, a numerical aperture at an optical disk side of an imaging optical system in which a light beam converged on an optical disk is minutely narrowed in diameter is enlarged to obtain the optical disk having a high density memory capacity. In this case, the degree of aberration occurring in the imaging optical system is increased because an optical axis of the system tilts from a normal line of the optical disk. As the numerical aperture is increased, the degree of the abberation is enlarged. To prevent the increase of the numerical aperture, it is effective to thin the thickness of the optical disk. The thickness of the optical disk denotes a distance from a surface of the optical disk (or an information medium) radiated by a light beam to an information recording plane on which a series of patterned pits are formed.

Fig. 3 shows a relationship between the thickness of the optical disk and the numerical aperture on condition that the tilt of the optical axis is constant.

As shown in Fig. 3, because the numerical aperture is 0.5 when the thickness of the optical disk is 1.2 mm, it is effective to thin the optical disk to 0.6 mm in thickness when the numerical aperture is increased to 0.6. In this case, even though the numerical aperture is increased on condition that the tilt of the optical axis is not changed, the degree of the aberration is not increased. Therefore, it is preferred that the thickness of the optical disk be thinned to obtain the optical disk having a high density memory capacity.

Accordingly, it is expected that the thickness of a prospective optical disk having a high density memory capacity becomes thinner than that of a present optical disk such as a compact disk appearing on the market now. For example, the thickness of the compact disk is about 1.2 mm, and the thickness of the prospective optical disk is expected to range from 0.4 mm to 0.8 mm.

An aim of the present invention is to provide a high density optical disk in which a series of first recording pits is formed to record pieces of information at high density on a thin substrate.

According to the present invention there is provided

an optical disk, comprising:

an information recording substrate having a first region having a first thickness T1, and a plurality of first recording pits placed at the first region of the information recording substrate for recording pieces of recording information at a first recording density;

characterised in that the information recording substrate also has a second region having a second thickness T2 larger than the first thickness T1;

and by a plurality of second recording pits placed at the second region of the information recording substrate for

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recording distinguishing information at a second recording density which is lower than the first recording density, the distinguishing information indicating that the first region of the information recording substrate has the first thickness T1.

In the above configuration, a substrate of a conventional compact disk has the same second thickness as that of the second region of the information recording substrate in the optical disk according to the present invention. Therefore, in cases where a beam of reproducing light is incident on a prescribed region of an unknown disk selected from a group of the conventional compact disk and the optical disk, the reproducing light is focused on a recording pit of the conventional compact disk or one of the second recording pits of the optical disk regardless of whether the unknown disk is the conventional compact disk or the optical disk.

In cases where the unknown disk is the optical disk, a piece of distinguishing information is read by the reproducing light. Because the distinguishing information informs that pieces of recording information are recorded on the information recording substrate having the first thickness, a curvature of the reproducing light is automatically changed to focus the reproducing light on the information recording substrate having the first thickness, and the reproducing light is automatically focused on one of the first recording pits. Therefore, a piece of recording information is reproduced.

In contrast, in cases where the unknown disk is the conventional compact disk, a piece of recording information is read by the reproducing light in the same manner as in a prior art.

Accordingly, a piece of recording information formed on an information recording substrate can be reliably reproduced even though the thickness of the infromation recording substrate is unknown.

The present invention also provides an optical disk, comprising:

an information recording substrate having a first thickness thinner than that of a compact disk;

a plurality of first recording pits placed at a first region of the information recording substrate for recording pieces of recording information at a first recording density;

characterised in that the information recording substrate additionally has a second region and by a plurality of second recording pits placed at a second region of the information recording substrate for recording distinguishing information at a second recording density lower than the first recording density, the distinguishing information indicating that the first region of the information recording substrate has the first thickness.

In the above configuration, a beam of reproducing light, of which a curvature is adjusted to focus the reproducing light on a recording pit formed on an information recording substrate of the compact disk, is incident on a prescribed region of an unknown disk selected from a group of the compact disk having an ordinary thickness and the optical disk according to the present invention, In cases where the unknown disk is the optical disk, the reproducing light is converged on one of the second recording pits in defocus because the information recording substrate of the optical disk has the thin thickness. However, because each of the second recording pits is large in size, a converging spot of the reproducing light is formed in the second recording pit. Therefore, a piece of distinguishing information is read by the reproducing light. Because the distinguishing information informs that pieces of recording information are recorded on the information recording substrate having the thin thickness, a curvature of the reproducing light is automatically changed to focus the reproducing light on the information recording substrate having the thin thickness, and the reproducing light is automatically focused on one of the first recording pits. Therefore, a piece of recording information is reproduced.

In contrast, in cases where the unknown disk is the compact disk, a piece of recording information is read by the reproducing light in the same manner as in a prior art.

Accordingly, a piece of recording information formed on an information recording substrate can be reliably reproduced even though the thickness of the information recording substrate is unknown.

The features and advantages of the present invention will become apparent from the following description of exemplary embodiments and the accompanying drawings, in which:-

Fig. 1 is a constitutional view of a conventional optical head apparatus proposed in Japanese Patent Application No. 46630 of 1991;

Figs. 2A, 2B are respectively a cross sectional view of a set of an objective lens and a blazed hologram shown in Fig. 1;

Fig. 3 shows a relationship between the thickness of an optical disk and a numerical aperture of an objective lens on condition that the tilt of the optical axis is constant;

Fig. 4A is a constitutional view of an imaging optical system having a compound objective lens according to a first reference apparatus, a beam of transmitted light not diffracted being converged on a thin type of information medium;

Fig. 4B is a constitutional view of the imaging optical system shown in Fig. 4A, a beam of first-order diffracted light being converged on a thick type of information medium;

Fig. 5 is a plan view of a hologram lens shown in Figs. 4A, 4B, a grating pattern of the hologram lens being depicted;

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Fig. 6 is a cross sectional view of the hologram lens shown in Fig. 5, the grating pattern formed in relief on the hologram lens being shown;

Fig. 7 is an explanatory diagram showing an intensity distribution of transmitted light L4 converged on a converging spot S1 of a first information medium, a primary maximum and secondary maxima suppressed occurring in the converging spot S1;

Fig. 8A is a cross sectional view of the hologram lens shown in Fig. 5, the grating pattern approximating to a stepwise shape composed of four stairs being shown;

Fig. 8B is a cross sectional view of the hologram lens shown in Fig. 5, the grating pattern approximating to a stepwise shape composed of a plurality of stairs being shown;

Fig. 9A is a constitutional view of an imaging optical system having a compound objective lens according to a modification of the first reference apparatus, a beam of first-order diffracted light being converged on a thin type of information medium;

Fig. 9B is a constitutional view of the imaging optical system shown in Fig. 9A, a beam of transmitted light not diffracted being converged on a thick type of information medium;

Fig. 10A is a constitutional view of an imaging optical system having a compound objective lens according to a second reference apparatus, a beam of transmitted light not diffracted being converged on a thin type of information medium;

Fig. 10B is a constitutional view of the imaging optical system shown in Fig. 10A, a beam of first-order diffracted light being converged on a thick type of information medium;

Fig. 11 shows a change of a diffraction efficiency of a hologram lens shown in Figs. 10A, 10B;

Figs. 12A to 12E are respectively a cross sectional view of the hologram lens shown in Figs. 10A, 10B, the grating pattern of the hologram lens approximating to a step-wise shape;

Fig. 13A shows an intensity distribution of incident light utilized in the second embodiment, a far field pattern of the incident light being distributed in a Gaussian distribution;

Fig. 13B shows an intensity distribution of transmitted light transmitting through a hologram lens shown in Figs. 10A, 10B, a far field pattern of the incident light being distributed in a gently-sloping shape;

Figs. 14A to 14C show intensity distributions of transmitted light and diffracted light transmitting through a hologram lens shown in Figs. 10A, 10B;

Fig. 15A is a plan view of a hologram lens according to a modification of the second reference apparatus, a grating pattern of the hologram lens being depicted;

Figs. 15B, 15C are respectively a constitutional view of an imaging optical system having a compound objective lens according to another modification of the second reference apparatus;

Fig. 16A is a constitutional view of an imaging optical system having a compound objective lens according to a third reference apparatus, a beam of first-order diffracted light being converged on a thin type of information medium;

Fig. 16B is a constitutional view of the imaging optical system shown in Fig. 16A, a beam of transmitted light not diffracted being converged on a thick type of information medium;

Fig. 17 shows a change of a diffraction efficiency of a hologram lens shown in Figs. 16A, 16B;

Figs. 18A to 18C show intensity distributions of transmitted light and diffracted light transmitting through a hologram lens shown in Figs. 16A, 16B;

Fig. 19A is a cross sectional view of a compound objective lens according to a fourth reference apparatus;

Fig. 19B is a cross sectional view of a compound objective lens according to a modification of the fourth reference apparatus;

Fig. 20 is a cross sectional view of a compound objective lens according to a fifth reference apparatus;

Fig. 21 is a constitutional view of an optical head apparatus according to a sixth reference apparatus;

Fig. 22 is a plan view of a wavefront changing device utilized in the six, ninth and twelfth reference apparatus, a grating pattern of a hologram lens utilized as the wavefront changing device being depicted;

Fig. 23 shows a positional relation between focal points of diffracted light occurring in the wavefront changing device shown in Fig. 22 and a photo detector;

Fig. 24 is a plan view of a photo detector utilized in the six, ninth, tenth, twelfth, thirteenth and seventeenth reference apparatus;

Fig. 25A and 25C respectively show a converging spot of first-order diffracted light radiated to detecting sections SE1, SE2 and SE3 of a sextant photo-detector shown in Fig. 24 and another converging spot of minus first-order diffracted light radiated to detecting sections SE4, SE5 and SE6 of the sextant photo-detector on condition that an objective lens shown in Fig. 21 is defocused on an information medium;

Fig. 25B shows a converging spot of first-order diffracted light radiated to the detecting sections SE1, SE2 and SE3 of the sextant photo-detector and another converging spot of minus first-order diffracted light radiated to the detecting sections SE4, SE5 and SE6 of the sextant photodetector on condition that the objective lens is just

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focused on the information medium;
Fig. 26 shows a relationship between beams of diffracted light occurring in the wavefront changing device shown in Fig. 22 and the photo detector shown in Fig. 24;
Fig. 27 is a constitutional view of an optical head apparatus according to a seventh reference apparatus;
Fig. 28 is a plan view of a photo detector utilized in the seven, ninth, tenth, twelfth and thirteenth reference apparatus;
Figs. 29A, 29B, 29C show various shapes of converging spots converged on the photo detector shown in Fig. 28;
Fig. 29D shows a radial direction Dr and a tangential direction Dt;
Fig. 30 is a constitutional view of an optical head apparatus according to a first modification of the seventh reference apparatus;
Fig. 31 is a constitutional view of an optical head apparatus according to a second modification of the seventh reference apparatus;
Fig. 32 is a constitutional view of an optical head apparatus according to a third modification of the seventh reference apparatus;
Fig. 33 is a constitutional view of an optical head apparatus according to a fourth modification of the seventh reference apparatus;
Fig. 34 shows a beam of transmitted light not diffracted on an incoming optical path and a beam of transmitted light diffracted on the incoming optical path, the beams being utilized to detect an information signal;
Fig. 35A graphically shows a change of a focus error signal obtained by detecting the intensity of transmitted light, the strength of the focus error signal depending on a distance between an objective lens and a first information medium;
Fig. 35B graphically shows a change of a focus error signal obtained by detecting the intensity of diffracted light, the strength of the focus error signal depending on a distance between an objective lens and a second information medium.
Fig. 36A graphically shows a change of a focus error signal obtained by detecting the intensity of diffracted light, the strength of the focus error signal depending on a distance between an objective lens and a first information medium;
Fig. 36B graphically shows a change of a focus error signal obtained by detecting the intensity of transmitted light, the strength of the focus error signal depending on a distance between an objective lens and a second information medium;
Fig. 37 is a constitutional view of an optical head apparatus according to a ninth reference apparatus;
Fig. 38 is a constitutional view of an optical head apparatus according to a tenth reference apparatus;
Fig. 39 is a plan view of a beam splitter having a reflection type of hologram utilized in the optical head apparatus shown in Fig. 38;
Figs. 40A, 40B are respectively a constitutional view of an optical head apparatus according to an eleventh reference apparatus;
Fig. 41 is a plan view of a beam splitter having a reflection type of hologram utilized in the optical head apparatus shown in Fig. 38;
Fig. 42A and 42C respectively show a converging spot of first-order diffracted light radiated to detecting sections SE1, SE2 and SE3 of a sextant photo-detector shown in Fig. 24 and another converging spot of minus first-order diffracted light radiated to detecting sections SE4, SE5 and SE6 of the sextant photo-detector on condition that diffracted light is converged in defocus on a second information medium;
Fig. 42B shows a converging spot of first-order diffracted light radiated to the detecting sections SE1, SE2 and SE3 of a sextant photo-detector shown in Fig. 24 and another converging spot of minus first-order diffracted light radiated to the detecting sections SE4, SE5 and SE6 of the sextant photo-detector on condition that diffracted light is converged in focus on a second information medium;
Fig. 43 is a constitutional view of an optical head apparatus according to a twelfth reference apparatus;
Fig. 44 is a constitutional view of an optical head apparatus according to a thirteenth reference apparatus;
Fig. 45 is a constitutional view of an optical head apparatus according to a fourteenth reference apparatus;
Fig. 46 is a plan view of a hologram lens utilized in the optical head apparatus shown in Fig. 45;
Fig. 47 is a constitutional view of an optical head apparatus to a fifteenth reference apparatus;
Fig. 48 is a plan view of a hologram lens utilized in the optical head apparatus shown in Fig. 47;
Figs. 49A, 49B respectively show a positional relation between unnecessary light occurring in the hologram lens shown in Fig. 48 and a photo detector shown in Fig. 47;
Fig. 50 is a constitutional view of an optical head apparatus according to a sixteenth reference apparatus;
Fig. 51 is a diagonal view of a light source and photo detectors utilized in the optical head apparatus shown in Fig. 50;
Fig. 52 is a constitutional view of an optical head apparatus according to a seventeenth reference apparatus;

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Fig. 53 is a diagonal view of a high density optical disk according to a first embodiment, a cross sectional view of the disk being partially shown;
Fig. 54 is a diagonal view of a high density optical disk according to a second embodiment, a cross sectional view of the disk being partially shown;
Fig. 55 is a block diagram of an optical disk apparatus with one of the optical head apparatuses shown in Figs. 21, 27, 30, 31, 32, 33, 37, 38, 40A, 43, 44, 50 and 52 according to a twentieth embodiment;
Fig. 56 is a flow chart showing the operation of the optical disk apparatus shown in Fig. 55.

(First reference apparatus)

Fig. 4A is a constitutional view of an imaging optical system having a compound objective lens according to a first reference apparatus, a beam of transmitted light not diffracted being converged on a thin type of information medium. Fig. 4B is a constitutional view of the imaging optical system shown in Fig. 4A, a beam of first-order diffracted light being converged on a thick type of information medium. Fig. 5 is a plan view of a hologram lens shown in Figs. 4A, 4B, a grating pattern of the hologram lens being depicted.

As shown in Figs. 4A, 4B, an imaging optical system 21 for converging light on a first substrate 22 of a thin type of first information medium 23 (a thickness T1) or a second substrate 24 of a thick type of second information medium 25 (a thickness T2) to form a diffraction-limited converging spot comprises a blazed hologram lens 26 for transmitting a part of incident light L3 radiated from a light source without any diffraction to form a beam of transmitted light L4 and diffracting a remaining part of the incident light L3 to form a beam of first-order diffracted light L5, and an objective lens 27 for converging the transmitted light L4 on the first information medium 23 or converging the first-order diffracted light L5 on the second information medium 25.

The first information medium 23 represents a prospective optical disk having a high density memory capacity, and the thickness T1 of the first information medium 23 ranges from 0.4 mm to 0.8 mm. The second information medium 25 represents a compact disk or a laser disk appearing on the market now, and the thickness T2 of the second information medium 25 is about 1.2 mm.

The term "convergence" denotes in this specification that divergent light or collimated light is focused to form a diffraction-limited micro spot.

In the above configuration, a part of incident light L3 collimated transmits through the hologram lens 26 without any diffraction, and a beam of transmitted light L4 (that is, a beam of zero-order diffracted light L4) is formed. Thereafter, the transmitted light L4 is converged by the objective lens 27. Also, a remaining part of the incident light L3 is diffracted and refracted by the hologram lens 26, and a beam of first-order diffracted light L5 is formed. In this case, the hologram lens 26 selectively functions as a concave lens for the first-order diffracted light L5, so that the first-order diffracted light L5 diverges from the hologram lens 26. Thereafter, the first-order diffracted light L5 is converged by the objective lens 27.

In cases where the thin type of first information medium 23 is utilized to record or reproduce pieces of information on or from a front surface of the medium 23, as shown in Fig. 4A, the transmitted light L4 is incident on a rear surface of the first information medium 23 and is focused on its front surface by the objective lens 27 to form a diffraction-limited converging spot S1 on the first information medium 23. In contrast, in cases where the thick type of second information medium 25 is utilized to record or reproduce pieces of information on or from a front surface of the medium 25, the diffracted light L5 is incident on a rear surface of the second information medium 25 and is focused on its front surface to form a diffraction-limited converging spot S2 on the second information medium 25. Because the hologram lens 26 functions as a concave lens to diverge the first-order diffracted light L5, the diffraction-limited converging spots S1, S2 are formed even though the thickness T1 of the first information medium 23 differs from the thickness T2 of the second information medium 25. Therefore, a compound objective lens 29 composed of the hologram lens 26 and the objective lens 27 has substantially two focal points.

As shown in Fig. 5, the hologram lens 26 is formed by drawing a grating pattern P1 in a pattern region 26A of a transparent substrate 28 in a concentric circle shape. The pattern region 26A is positioned in a center portion of the transparent substrate 28, and a no-pattern region 26B is positioned in a peripheral portion of the transparent substrate 28 to surround the pattern region 26A. An optical axis of the imaging optical system 21 passes through a central point of the grating pattern P1 and a central axis of the objective lens 27.

In addition, as shown in Fig. 6, the grating pattern P1 of the hologram lens 26 is formed in relief to produce a phase modulation type of hologram lens. That is, blocks which each are composed of a bottom portion and a top portion are concentrically, formed in the grating pattern P1. The height H of the relief in the grating pattern P1 is set to:

$$H < \lambda/(n(\lambda)-1), \quad (1)$$

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where the symbol λ denotes a wavelength of the incident light L3 and the symbol $n(\lambda)$ denotes a refractive index of the transparent substrate 28 for the incident light L3. In this case, a difference in phase modulation degree between the incident light L3 transmitting through a bottom portion of the grating pattern P1 and the incident light L3 transmitting through a top portion of the grating pattern P1 is lower than 2π radians. Therefore, a diffraction efficiency of the hologram lens 26 for the incident light L3 transmitting through the grating pattern P1 is less than 100 % to generate the light L4 transmitting through the grating pattern P1. Also, the incident light L3 transmitting through the no-pattern region 26B is not diffracted. As a result, the intensity of the transmitted light L4 can be sufficient to record or reproduce pieces of information on or from the first information medium 23.

Also, because the intensity of the transmitted light L4 is sufficient over the entire surface of the hologram lens 26, secondary maxima (side lobes) of the transmitted light L4 undesirably occurring in the converging spot S1 can be suppressed. In detail, as an intensity distribution of the transmitted light L4 converged on the converging spot S1 is shown in Fig. 7, a primary maximum (a main lobe) of the transmitted light L4 positioned in a center of the converging spot S1 is utilized to record or reproduce a piece of information on or from the first information medium 23, and secondary maxima positioned around the primary maximum are unnecessary because the secondary maxima deteriorate a recording pit or a reproducing signal formed by the primary maximum.

The grating pattern P1 of hologram lens 26 formed in relief is blazed as shown in Fig. 6, so that the occurrence of minus first-order diffracted light is considerably suppressed. Therefore, the intensity sum of the transmitted light L4 and the first-order diffracted light L5 is maximized. In other words, a utilization efficiency of the incident light L3 is enhanced.

The numerical aperture NA of the objective lens 27 is equal to or more than 0.6. Also, when the transmitted light L4 is converged by the objective lens 27, the diffraction-limited converging spot S1 is formed on the first information medium 23 having a thickness T1.

A diameter of the hologram lens 26 is almost the same as an aperture of the objective lens 27, so that a diameter of the pattern region 26A is smaller than the aperture of the objective lens 27. Because the incident light L3 transmitting through the no-pattern region 26B is not diffracted, not only the light L4 transmitting through the pattern region 26A but also the light L4 transmitting through the no-pattern region 26B are converged on the first information medium 23 by the objective lens 27 having a high numerical aperture. Therefore, the intensity of the transmitted light L4 converged at the converging point S1 can be increased. In contrast to the transmitted light L4, only the incident light L3 transmitting through the pattern region 26A of the hologram lens 26 is changed to the first-order diffracted light L5, and the first-order diffracted light L5 is converged on the second information medium 25 by the objective lens 27 having substantially a low numerical aperture.

The phase of the light L4 transmitting through the grating pattern P1 of the pattern region 26A is determined by an average value of the phase modulation degrees in the light L4 transmitting through the bottom and top portions of the grating pattern P1. In contrast, because the height of the no-pattern region 26B is constant, the phase of the light L4 transmitting through the no-pattern region 26B is modulated at a phase modulation degree. Therefore, as shown in Fig. 6, the height of the no-pattern region 26B is set even with an average height of the grating pattern P1 to enhance the convergence function of the objective lens 27.

For example, as shown in Fig. 8A, in cases where each block of the grating pattern P1 in the hologram lens 26 shown in Fig. 6 approximates to a step-wise shape composed of four stairs, a first step is etched at a depth h1+h2 and a width W1, a second step is etched at a depth hl and a width W2, a third step is etched at a depth h2 and a width W2, and a fourth step is etched at a width W1. Therefore, the grating pattern P1 approximating to the step-wise shape is formed in the pattern region 26A. Thereafter, a peripheral portion of the transparent substrate 28 is etched by a depth h1 or h2 to form the no-pattern region 26B. Therefore, the height of the no-pattern region 26B is almost the same as an average height of the pattern region 26A, so that the phase of the light L4 transmitting through the pattern region 26A is almost the same as that of the light L4 transmitting through the no-pattern region 26B.

In addition, as shown in Fig. 8B, an ideal blazed shape of the hologram lens 26 shown in Fig. 6 can approximate to a step-wise shape which is obtained by etching a center portion of the transparent substrate 28 many times. In this case, the height H0 of the step-wise shape is set to satisfy an equation $H0 < \lambda/(n(\lambda)-1)$ so that the difference in phase modulation degree is set to a value lower than 2π radians. Specifically, in cases where the step-wise shape of the hologram lens 26 is composed of a flight of N stairs having the same difference n_o in level, the difference n_o in level is set to satisfy an equation $n_o < \lambda/\{(n(\lambda)-1)*N\}$ to set the difference in phase modulation degree of each stairs to a value lower than $2\pi/N$ radians. A peripheral portion of the transparent substrate 28 is etched to set the thickness of the no-pattern region 26B to a thickness of the pattern region 26A at one of the N stairs which is not the top stair or the bottom stair. Therefore, the height of the no-pattern region 26B is almost the same as an average height of the pattern region 26A, so that the phase of the light L4 transmitting through the pattern region 26A is almost the same as that of the light L4 transmitting through the no-pattern region 26B.

The grating pattern P1 of the hologram lens 26 is designed to correct any aberration occurring in the objective lens 27 and the second information medium 25, so that the first-order diffracted light L5 transmits through the second

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information medium 25 having a thickness T2 and is converged on the medium 25 to form the diffraction-limited converging spot S2 without any aberration. A method for designing the hologram lens 26 having an aberration correcting function is described.

After the first-order diffracted light L5 is converged on the second information medium 25, spherical waves diverge from the converging spot S2 and transmit through the second substrate 24 and the objective lens 27. Thereafter, the spherical waves transmit through the transparent substrate 28 and optically interfere with the incident light L3. Therefore, an interference pattern is formed by the interference between the spherical waves and the incident light L3. The interference pattern can be calculated by subtracting the phase of the spherical waves from an inverted phase obtained by inverting the phase of the incident light L3. Accordingly, the grating pattern P1 of the hologram lens 26 which agrees with the interference pattern calculated can be easily formed according to a computer generated hologram technique.

Accordingly, because the compound objective lens 29 is composed of the objective lens 27 and the hologram lens 26 in which a part of the incident light L3 is diffracted and refracted, a diffraction-limited converging spot can be reliably formed on an information medium regardless of whether the information medium has a thickness T1 or a thickness T2. Also, two diffraction-limited converging spots can be simultaneously formed on an information medium at difference depths. In other words, the compound objective lens has substantially two focal points.

Also, because the diffraction efficiency of the hologram lens 26 is less than 100 % and the intensity of the light L4 transmitting through the hologram lens 26 is sufficient to record or reproduce information on or from the first information medium 23, the secondary maxima of the transmitted light L4 converged on the converging spot S1 can be suppressed.

Also, because the hologram lens 26 is blazed, the occurrence of minus first-order diffracted light can be considerably suppressed. Therefore, the intensity sum of the transmitted light L4 and the first-order diffracted light L5 can be maximized, and a utilization efficiency of the incident light L3 can be enhanced.

Also, because the hologram lens 26 functions as a lens only for the first-order diffracted light, the position of the converging point S1 formed by the transmitted light L4 differs from that of the converging point S2 formed by the first-order diffracted light L5 in an optical axis direction. Therefore, when the transmitted light L4 is converged in focus on an information recording plane of the information medium 23 to record or read a piece of information, the first-order diffracted light L5 converged on the information medium 23 is out of focus at the information recording plane. In the same manner, when the first-order diffracted light L5 is converged in focus on an information recording plane of the information medium 25, the transmitted light L4 converged on the information medium 25 is out of focus at the information recording plane. Accordingly, when the light L4 (or L5) is converged on the converging spot S1 (or S2) in focus to record or read the information, the light L5 (or L4) not converged on the converging spot S1 (or S2) in focus does not adversely influence on the recording or reading of the information. To reliably prevent the adverse influence on the recording or reading of the information, a difference in the optical axis direction between the converging spots S1, S2 is required to be equal to or more than 50 μm. That is, when the difference is equal to or more than 50 μm, the light L5 (or L4) largely diverges to reduce the intensity of the light L5 (or L4) at an information recording plane when the light L4 (or L5) is converged on the converging spot S1 (or S2) of the information recording plane at a high intensity.

Also, because the thickness T2 of the second information medium 25 representing the compact disk or the laser disk is about 1. 2 mm and because the thickness T1 of the first information medium 23 representing a prospective optical disk ranges from 0.4 mm to 0.8 mm, the difference in the optical axis direction between the converging points S1, S2 is required to be equal to or less than 1.0 mm by considering a moving range of an actuator with which the position of the compound objective lens 29 composed of the objective lens 27 and the hologram lens 26 is adjusted according to a focus servo signal. Because the hologram lens 26 functions as a concave lens for the first-order diffracted light, the difference between the converging points S1, S2 can be increased to about 1 mm.

Accordingly, even though the transmitted light L4 and the first-order diffracted light L5 are simultaneously converged by the objective lens 27, no adverse influence is exerted on the recording or reproduction of the information on condition that the difference between the converging points S1, S2 ranges from 50 μm to 1 mm.

Examples of the utilization of the imaging optical system 21 for various types of optical disks are described.

In cases where the image optical system 21 is utilized for an optical disk device in which pieces of information recorded in a thin type of high density optical disk and a thick type of compact disk are exclusively reproduced, the diffraction efficiency of the hologram lens 26 for changing the incident light L3 to the diffracted light L5 is set in a range from about 20 % to 70 %. In this case, the intensity of the transmitted light L4 converged on the high density optical disk is almost the same as that of the first-order diffracted light L5 converged on the compact disk. Therefore, the output power of the incident light L3 can be minimized.

Also, in cases where the image optical system 21 is utilized for an optical disk device in which pieces of information recorded in a thin type of high density optical disk are recorded or reproduced and pieces of information recorded in a thick type of optical disk are exclusively reproduced, the diffraction efficiency of the hologram lens 26 for changing the incident light L3 to the first-order diffracted light L5 is set to a value equal to or lower than 30 %. In this case, even though a high intensity of transmitted light L4 is required to record a piece of information on the high density optical disk, the recording of the information can be reliably performed without increasing the intensity of the incident light L3

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because a transmission efficiency of the hologram lens 26 for the incident light L3 is high. In other words, a utilization efficiency of the incident light L3 can be enhanced when a piece of information is recorded on the high density optical disk, so that the output power of the incident light L3 can be minimized.

In the first reference apparatus, the hologram lens 26 functions as a concave lens for the first-order diffracted light L5. However, it is applicable that a hologram lens 26M functioning as a convex lens for the first-order diffracted light L5 be utilized in place of the hologram lens 26. That is, as shown in Figs. 9A, 9B, the diffracted light L5 is converged on the first information medium 23 by the objective lens 27 to form the diffraction limited converging spot S1, and the transmitted light L4 is converged on the second information medium 25 by the objective lens 27 to form the diffraction limited converging spot S2. In this case, the difference between the converging points S1, S2 is required to be equal to or less than 0.5 mm by considering the moving range of the actuator. However, the occurrence of a chromatic aberration can be prevented in an imaging optical system 21M in which the hologram lens 26M functioning as a concave lens for the diffracted light L5 is utilized. The achromatization function in the imaging optical system is described in detail. When a focal length of the hologram lens 26M for the incident light L3 having a wavelength λ_0 is represented by f_{H0} and another focal length of the hologram lens 26M for the incident light L3 having a wavelength λ_1 is represented by f_{H1}, an equation (2) is satisfied.

$$f_{H1} = f_{H0} \times \lambda_0 / \lambda_1 \tag{2}$$

The focal length f_H of the hologram lens 22 is shortened as the wavelength λ of the incident light L3 becomes longer. Also, when a refractive index of the objective lens 27 for the incident light L3 having a wavelength λ_0 is represented by $n(\lambda_0)$ and another refractive index of the objective lens 27 for the incident light L3 having a wavelength λ_1 is represented by $n(\lambda_1)$, a focal length $f_D(\lambda)$ of the objective lens 27 for the incident light L3 having a wavelength λ is formulated by an equation (3).

$$f_D(\lambda_1) = f_D(\lambda_0) \times (n(\lambda_0) - 1)/(n(\lambda_1) - 1) \tag{3}$$

The focal length $f_D(\lambda)$ of the objective lens 27 is lengthened as the wavelength λ of the incident light L3 becomes longer. That is, the dependence of the focal length $f_D(\lambda)$ on the wavelength λ in the objective lens 27 is opposite to that of the focal length f_H on the wavelength λ in the hologram lens 26M. Therefore, a condition that the compound objective lens 29M composed of the objective lens 27 and the hologram lens 26M functions as an achromatic lens is formulated by an equation (4).

$$\begin{aligned} 1/f_{H0} + 1/f_D(\lambda_0) &= 1/f_{H1} + 1/f_D(\lambda_1) \\ &= 1/(f_{H0} \times \lambda_0/\lambda_1) + \\ &(n(\lambda_1) - 1)/\{f_D(\lambda_0) \times (n(\lambda_0) - 1)\} \end{aligned} \tag{4}$$

Accordingly, because the dependence of the focal length $f_D(\lambda)$ on the wavelength λ in the objective lens 27 is opposite to that in the hologram lens 22, the compound objective lens 29M having an achromatic function can be formed by the combination of the lenses 26M, 27, and the occurrence of the chromatic aberration can be prevented. Also, even though the equation (4) is not strictly satisfied, the occurrence of the chromatic aberration can be largely suppressed.

Also, a curvature of the objective lens 27 can be small because the hologram lens 26M functions as a convex lens for the first-order diffracted light L5. Also, because the hologram lens 26M is a plane type of element, a lightweight type of compound objective lens having an achromatic function can be made in large scale manufacture. A principal of the achromatization has been proposed in a first literature (D. Faklis and M. Morris, Photonics Spectra(1991), November p.205 & December p.131), a second literature (M.A. Gan et al., S.P.I.E.(1991), Vol.1507, p.116), and a third literature (P. Twardowski and P. Meirueis, S.P.I.E.(1991), Vol.1507, p.55).

(Second Reference Apparatus)

Fig. 10A is a constitutional view of an imaging optical system having a compound objective lens according to a second reference apparatus, a beam of transmitted light not diffracted being converged on a thin type of information

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medium. Fig. 10B is a constitutional view of the imaging optical system shown in Fig. 10A, a beam of first-order diffracted light being converged on a thick type of information medium.

As shown in Figs. 10A, 10B, an imaging optical system 31 for converging light on the first substrate 22 of the first information medium 23 (the thickness T1) or the second substrate 24 of the second information medium 25 (the thickness T2) to form a diffraction-limited converging spot, comprises a blazed hologram lens 32 for transmitting a part of incident light L3 without any diffraction to form a beam of transmitted light L4 and diffracting a remaining part of incident light L3 to form a beam of first-order diffracted light L5, and the objective lens 27 for converging the transmitted light L4 on the first information medium 23 or converging the first-order diffracted light L5 on the second information medium 25.

The hologram lens 32 is formed by drawing a grating pattern P2 in a pattern region 32A of the transparent substrate 28 in a concentric circle shape. The pattern region 32A is positioned in a center portion of the transparent substrate 28. An diameter of the grating pattern P2 is equal to or larger than an aperture of the objective lens 27. Also, a diffraction efficiency of the hologram lens 32 for the incident light L3 transmitting through the grating pattern P2 is less than 100 % in the same manner as in the first embodiment, so that the intensity of the transmitted light L4 is sufficient to record or reproduce a piece of information on or from the first information medium 23.

In addition, as shown in Fig. 11, the diffraction efficiency in a central portion of the pattern region 32A is high, and the diffraction efficiency is gradually decreased toward an outer direction of the pattern region 32A. In other words, in cases where the grating pattern P2 of the hologram lens 32 is formed in relief, the height H of the relief in the grating pattern P2 is gradually lowered toward the outer direction of the pattern region 32A. Or, in cases where an ideal blazed shape of the hologram lens 26 approximates to a step-wise shape, each block of the grating pattern P2 positioned in the central portion of the transparent substrate 28 is formed in a step-wise shape shown in Fig. 12A in which an inclined angle θ_1 of stairs is large and a relationship W1>W2 between a first etching width W1 and a second etching width W2 is satisfied, and the grating pattern P2 formed in the step-wise shape shown in Fig. 12A is gradually changed by decreasing the first etching width W1 and increasing the second etching width W2 toward the outer direction of the pattern region 32A while the height H of the grating pattern P2 is gradually decreased. Therefore, each block of the grating pattern P2 positioned in a peripheral portion of the transparent substrate 28 is formed in a step-wise shape shown in Fig. 12B in which an inclined angle θ_2 of stairs is small and a relationship W1<W2 between the etching widths is satisfied. Also, each block of the grating pattern P2 positioned in a middle portion between the central and peripheral portions is formed in a step-wise shape shown in Fig. 12C in which the etching widths W1, W2 is the same.

In the above configuration of the imaging optical system 31, a part of the incident light L3 transmits through the hologram lens 32 without any diffraction to form a beam of transmitted light L4, and the transmitted light L4 is converged by the objective lens 27. Also, a remaining part of the incident light L3 is diffracted and refracted by the hologram lens 32. In this case, the hologram lens 32 functions as a concave lens for the incident light L3, so that a first-order diffracted light L5 diverges from the hologram lens 32. Thereafter, the first-order diffracted light L5 is converged by the objective lens 27.

In cases where the thin type of first information medium 23 is utilized to record or reproduce pieces of information on or from a front surface of the medium 23, as shown in Fig. 10A, the transmitted light L4 is incident on a rear surface of the first information medium 23 and is focused on its front surface by the objective lens 27 to form a diffraction-limited converging spot S3 on the first information medium 23. In this case, because the diffraction efficiency in the central portion of the grating pattern P2 is high and because the diffraction efficiency is gradually decreased toward the outer direction of the grating pattern P2, a diffraction probability of the incident light L3 is lowered in the peripheral portion of the grating pattern P2. Therefore, the light L4 transmits through the objective lens 27 on condition that the numerical aperture NA of the objective lens 27 is high.

In contrast, in cases where the thick type of second information medium 25 is utilized to record or reproduce pieces of information on or from a front surface of the medium 25, the diffracted light L5 is incident on a rear surface of the second information medium 25 and is focused on its front surface to form a diffraction-limited converging spot S5 on the second information medium 25. In this case, because the hologram lens 32 functions as a concave lens to diverge the first-order diffracted light L5, the diffraction-limited converging spots S3, S4 are formed even though the thickness T1 of the first information medium 23 differs from the thickness T2 of the second information medium 25. Therefore, a compound objective lens 34 composed of the hologram lens 32 and the objective lens 27 has substantially two focal points.

Accordingly, because the light L4 transmits through the objective lens 27 on condition that the numerical aperture NA of the objective lens 27 is high, the intensity of the transmitted light L4 converged on the first information medium 23 can be high.

Also, in cases where the incident light L3 is radiated from a semiconductor laser, a far field pattern of the incident light L3 is distributed in a Gaussian distribution as shown in Fig. 13A. Therefore, because the diffraction efficiency is gradually decreased toward the outer direction of the grating pattern P2, a far field pattern of the transmitted light L4 is distributed in a gently-sloping shape as shown in Fig. 13B. In contrast to the second embodiment, because the

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incident light L3 is not diffracted in the no-pattern region 26b of the hologram lens 26 in the first embodiment, the intensity of the transmitted light L4 is suddenly increased at the peripheral portion of the hologram lens 26.

Accordingly, secondary maxima of the transmitted light L4 converged on the converging spot S3 can be moreover suppressed in the second embodiment as compared with in the first embodiment. That is, the recording and reproducing of the information can be performed without any deterioration of the information by utilizing the imaging optical system 31.

In addition, in cases where the first-order diffracted light L5 is converged on the second information medium 25 to form the diffraction-limited converging spot S4, a numerical aperture of the objective lens 27 for the first-order diffracted light L5 is low because the diffraction efficiency of the hologram lens 32 is decreased toward an outer direction of the pattern region 32A. As a result, the intensity of the first-order diffracted light L5 becomes lowered. In cases where the diffraction efficiency of the hologram lens 32 is heightened to increase the intensity of the first-order diffracted light L5, the intensity of the transmitted light L4 at its inner beam portion is largely decreased, and secondary maxima (or side lobes) of the transmitted light L4 at the converging spot S3 is undesirably increased. Therefore, the incident light L3 of which the far field pattern is distributed in the Gaussian distribution is radiated to the hologram lens 32 to increase the intensity of the first-order diffracted light L5 without any increase of the second maxima. In detail, as shown in Fig. 14A, the incident light L3 distributed not only in a central portion of the Gaussian distribution but also in a peripheral portion of the Gaussian distribution transmits through the hologram lens 32 and is refracted by the objective lens 27 because the diameter of the grating pattern P2 is equal to or larger than the aperture of the objective lens 27. Therefore, a numerical aperture NA of the objective lens 27 at a light source side for the incident light L3 becomes higher than that in the first embodiment, and the diffraction efficiency of the hologram lens 32 is heightened. As a result, the intensity of the first-order diffracted light L5 converged on the second information medium 25 can be increased, as shown in Fig. 14B. Also, because the intensity of the incident light L3 at the peripheral portion of the Gaussian distribution is low and because the diffraction efficiency of the hologram lens 32 is increased toward the inner direction of the grating pattern region 32A, intensity of the transmitted light L4 is distributed in a gently-sloping shape as shown in Fig. 14C. Accordingly, secondary maxima of the transmitted light L4 at the converging spot S3 can be suppressed.

Examples of the utilization of the imaging optical system 31 for various types of optical disks are described.

In cases where the image optical system 31 is utilized for an optical disk device in which pieces of information recorded in a thin type of high density optical disk and a thick type of compact disk are exclusively reproduced, the diffraction efficiency of the hologram lens 32 for the incident light L3 is set in a range from about 20 % to 70 %. In this case, the intensity of the transmitted light L4 converged on the high density optical disk is almost the same as that of the first-order diffracted light L5 converged on the compact disk. Therefore, the output power of the incident light L3 can be minimized.

Also, in cases where the image optical system 31 is utilized for an optical disk device in which pieces of information recorded in a thin type of high density optical disk are recorded or reproduced and pieces of information recorded in a thick type of optical disk are exclusively reproduced, the diffraction efficiency of the hologram lens 32 for the incident light L3 is set to a value equal to or lower than 30 %. In this case, even though a high intensity of transmitted light L4 is required to record a piece of information on the high density optical disk, the recording of the information can be reliably performed without increasing the intensity of the incident light L3 because a transmission efficiency of the hologram lens 32 for the incident light L3 is high. In other words, a utilization efficiency of the incident light L3 can be enhanced when a piece of information is recorded on the high density optical disk, so that the output power of the incident light L3 can be minimized.

In the second reference apparatus, the grating pattern P2 positioned in the central portion of the transparent substrate 28 is gradually changed toward the outer direction of the pattern region 32A from the step-wise shape shown in Fig. 12A to the step-wise shape shown in Fig. 12B through the step-wise shape shown in Fig. 12C. However, because the occurrence of unnecessary diffracted light such as minus first-order diffracted light can be effectively prevented in the middle portion of the transparent substrate 28 in which the grating pattern P2 is formed in the step-wise shape shown in Fig. 12C, it is preferred that the middle portion occupy a large part of the pattern region 32A of the hologram lens 32. In this case, the intensity sum of the transmitted light L4 and the first-order diffracted light L5 can be maximized, so that a utilization efficiency of the incident light L3 can be enhanced.

Also, because the first etching width W1 of the grating pattern P2 is gradually decreased toward the outer direction of the pattern region 32A, it is applicable that the grating pattern P2 formed in the step-wise shape shown in Fig. 12B be changed to a step-wise shape shown in Fig. 12D when the first width W1 is decreased to a value lower than about 1 μm. That is, a flight of four stairs shown in Fig. 12B is changed to a flight of two stairs. In this case, the grating pattern P2 formed in the step-wise shape shown in Fig. 12D can be easily made. In addition, in cases where a height H4 of the grating pattern P2 formed in the step-wise shape shown in Fig. 12D is moreover decreased toward the outer direction of the pattern region 32A, it is preferred that the grating pattern P2 be formed in a step-wise shape shown in Fig. 12E. That is, a third etching width W3 is gradually decreased toward the outer direction of the pattern region 32A while decreasing a height H5 of the grating pattern P2. Therefore, the diffraction efficiency of the hologram lens 32

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can be gradually decreased toward the outer direction of the pattern region 32A without any manufacturing difficulty of the grating pattern P2.

In addition, as shown in Fig. 15A, it is applicable that a hologram lens 33 be formed, in place of the hologram lens 32, by placing the grating pattern P1 of the pattern region 32A in a central portion of the transparent substrate 28 and placing four types of diffraction regions 33A, 33B, 33C and 33D which surround the grating pattern P1. A part of the incident light L3 transmitting through each of the diffraction regions 33A to 33D is diffracted to control a transmission efficiency of the hologram lens 33. In this case, the intensity of the transmitted light L4 at its peripheral portion is decreased, so that secondary maxima occurring in the converging spot S3 can be suppressed. Also, it is applicable that the grating pattern P1 of the hologram be replaced with the grating pattern P2. Also, it is applicable that grating directions of the diffraction regions 33A to 33D differ from each other. In this case, even though the first-order diffracted light L5 diffracted in the diffraction region 33A is, for example, incident on the diffraction region 33c after the diffracted light L5 is reflected by the second information medium 25, the diffracted light L5 again diffracted in the diffraction region 33c does not pass in parallel to the optical axis. Therefore, in cases where a piece of information read from the second information medium 25 is detected in a detector to reproduce the information, the first-order diffracted light L5 diffracted in the diffraction regions 33A to 33D is not detected by the detector as stray light. Accordingly, the reproduction of the information does not deteriorate.

Also, as shown in Fig. 15B, it is applicable that the hologram lens 32 function as a convex lens. In this case, the diffracted light L5 is converged on the first information medium 23, and the transmitted light L4 is converged on the second information medium 25, as shown in Fig. 15C.

(Third Reference Apparatus)

Fig. 16A is a constitutional view of an imaging optical system having a compound objective lens according to a third reference apparatus, a beam of first-order diffracted light being converged on a thin type of information medium. Fig. 16B is a constitutional view of the imaging optical system shown in Fig. 16A, a beam of transmitted light not diffracted being converged on a thick type of information medium.

As shown in Figs. 16A, 16B, an imaging optical system 41 for converging light on the first substrate 22 of the first information medium 23 (the thickness T1) or the second substrate 24 of the second information medium 25 (the thickness T2) to form a diffraction-limited converging spot comprises a blazed hologram lens 42 for transmitting a part of incident light L3 without any diffraction to form a beam of transmitted light L4 and diffracting a remaining part of incident light L3 to form a beam of first-order diffracted light L6, and the objective lens 27 for converging the first-order diffracted light L6 on the first information medium 23 or converging the transmitted light L4 on the second information medium 25.

The hologram lens 42 is formed by drawing a grating pattern P3 in a pattern region 42A of the transparent substrate 28 in a concentric circle shape. The pattern region 42A is positioned in a center portion of the transparent substrate 28. An diameter of the grating pattern P3 is equal to or larger than an aperture of the objective lens 27. Also, a diffraction efficiency of the hologram lens 42 for the incident light L3 transmitting through the grating pattern P3 is less than 100 % in the same manner as in the first embodiment, so that the intensity of the transmitted light L4 is sufficient to record or reproduce a piece of information on or from the second information medium 25.

In addition, as shown in Fig. 17, the diffraction efficiency, of the hologram lens 42 is high in a peripheral portion of the pattern region 42A, and the diffraction efficiency is gradually decreased toward an inner direction of the pattern region 42A. In other words, in cases where the grating pattern P3 of the hologram lens 42 is formed in relief, the height H of the relief in the grating pattern P3 is gradually lowered toward the inner direction of the pattern region 42A. Or, in cases where an ideal blazed shape of the hologram lens 26 approximates to a step-wise shape, each pitch of the grating pattern P3 positioned in the peripheral portion of the transparent substrate 28 is formed in a step-wise shape shown in Fig. 12A in which the inclined angle θ_1 of stairs is large and the relationship W1>W2 between the first and second etching widths W1, W2 is satisfied, and the grating pattern P3 formed in the step-wise shape shown in Fig. 12A is gradually changed by decreasing the first etching width W1 and increasing the second etching width W2 toward the inner direction of the pattern region 42A while the height H of the grating pattern P3 is gradually decreased. Therefore, each pitch of the grating pattern P3 positioned in a central portion of the transparent substrate 28 is formed in a step-wise shape shown in Fig. 12B in which the inclined angle θ_2 of stairs is small and the relationship W1<W2 is satisfied. Also, each pitch of the grating pattern P3 positioned in a middle portion between the central and peripheral portions is formed in a step-wise shape shown in Fig. 12C in which the etching widths W1, W2 is the same.

In the above configuration of the imaging optical system 41, as shown in Fig. 16B, a part of the incident light L3 transmits through the hologram lens 42 without any diffraction to form a beam of transmitted light L4, and the transmitted light L4 is converged by the objective lens 27. Also, a remaining part of the incident light L3 is diffracted by the hologram lens 42 to form a beam of first-order diffracted light L6. In this case, the hologram lens 42 functions as a convex lens for the incident light L3, so that a first-order diffracted light L6 formed in the hologram lens 42 converges. Thereafter, the diffracted light L6 is converged by the objective lens 27.

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In cases where the thin type of first information medium 23 is utilized to record or reproduce pieces of information on or from a front surface of the medium 23, as shown in Fig. 16A, the diffracted light L6 is incident on a rear surface of the first information medium 23 and is focused on its front surface to form a diffraction-limited converging spot S5 on the first information medium 23. In contrast, in cases where the thick type of second information medium 25 is utilized to record or reproduce pieces of information on or from a front surface of the medium 25, the transmitted light L4 is incident on a rear surface of the second information medium 25 and is focused on its front surface to form a diffraction-limited converging spot S6 on the second information medium 25.

In this case, because the hologram lens 42 functions as a convex lens to converge the diffracted light L6, the diffraction-limited converging spots S5, S6 are formed even though the thickness T1 of the first information medium 23 differs from the thickness T2 of the second information medium 25. Therefore, a compound objective lens 43 composed of the hologram lens 42 and the objective lens 27 has substantially two focal points.

Also, because the hologram lens 42 functions as a convex lens for the diffracted light L6, the diffracted light L6 transmits through the objective lens 27 on condition that the numerical aperture NA of the objective lens 27 is substantially high.

In addition, because the diffraction efficiency in the peripheral portion of the grating pattern P3 is high and because the diffraction efficiency is gradually decreased toward the inner direction of the grating pattern P3, a diffraction probability of the incident light L3 is higher in the peripheral portion of the grating pattern P3.

The grating pattern P3 of the hologram lens 42 is designed to correct any aberration occurring in the objective lens 27 and the first information medium 23, so that the diffracted light L6 transmits through the first information medium 23 having the thickness T1 and is converged on the medium 23 to form the diffraction-limited converging spot S5 without any aberration. A method for designing the hologram lens 42 having an aberration correcting function is described.

After the diffracted light L6 is converged on the first information medium 23, spherical waves diverge from the converging spot S5 and transmit through the first substrate 22 and the objective lens 27. Thereafter, the spherical waves transmit through the transparent substrate 28 and optically interfere with the incident light L3. Therefore, an interference pattern is formed by the interference between the spherical waves and the incident light L3. The interference pattern can be calculated by adding the phase of the spherical waves to an inverted phase obtained by inverting the phase of the incident light L3. Accordingly, the grating pattern P3 of the hologram lens 42 which agrees with the interference pattern calculated can be easily formed according to a computer generated hologram technique.

Accordingly, because the hologram lens 42 functions as a convex lens for the first-order diffracted light L6, a curvature of the objective lens 27 can be lowered. Also, a glass material having a high refractive index is not required to produce the objective lens 27.

Also, because the first-order diffracted light L6 formed in the hologram lens 42 converges before the diffracted light L6 is incident on the objective lens 27, the distance in an optical axis direction between the converging spots S5, S6 can be lengthened to about 1 mm. Therefore, even though the transmitted light L4 (or the first-order diffracted light L6) is converged on the converging spot S6 (or S5) in focus to record or read a piece of information, the light L6 (or L4) is not converged on the converging spot S6 (or S5) in focus to reduce the intensity of the light L6 (or L4) at the converging spot S6 (or S5). Accordingly, no adverse influence is exerted on the recording or reproduction of the information

Also, because the hologram lens 42 functions as a convex lens for the first-order diffracted light L6, the occurrence of a chromatic aberration can be prevented in the imaging optical system 41. In detail, the focal length of the hologram lens 42 is shortened as the wavelength of the incident light L3 becomes longer. In contrast, the focal length of the objective lens 27 is lengthened as the wavelength of the incident light L3 becomes longer. That is, the dependence of the focal length on the wavelength in the objective lens 27 is opposite to that of the focal length on the wavelength in the hologram lens 42. Therefore, the compound objective lens 43 having an achromatic function can be formed by the combination of the lenses 27, 42, and the occurrence of the chromatic aberration can be prevented.

Also, because the hologram lens 42 is a plane type of element, a lightweight type of compound objective lens can be made in large scale manufacture.

Also, because the diffraction efficiency of the hologram lens 42 is gradually decreased toward an inner direction of the pattern region 42A, the numerical aperture of the objective lens 27 for the first-order diffracted light L6 becomes substantially enlarged. Therefore, the intensity of the first-order diffracted light L6 can be enlarged to record or reproduce a piece of information on or from the first information medium 23.

Also, in cases where the incident light L3 is radiated from a semiconductor laser, a far field pattern of the incident light L3 is distributed in a Gaussian distribution as shown in Fig. 13A. Therefore, because the diffraction efficiency of the hologram lens 42 is gradually decreased toward the inner direction of the grating pattern P2, a far field pattern of the first-order diffracted light L6 is distributed in a gently-sloping shape. Accordingly, secondary maxima of the first-order diffracted light L6 converged on the converging spot S5 can be moreover suppressed in the third embodiment as compared with in the first embodiment. That is, the recording and reproducing of the information can be performed

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without any deterioration of the information by utilizing the imaging optical system 41.

In addition, in cases where the transmitted light L4 is converged on the second information medium 25 to form the diffraction-limited converging spot S6, a numerical aperture of the objective lens 27 for the transmitted light L4 is low because the diffraction efficiency of the hologram lens 42 is increased toward an outer direction of the grating pattern 42A. As a result, the intensity of the transmitted light L4 becomes lowered. In cases where a transmission efficiency of the hologram lens 42 is heightened to increase the intensity of the transmitted light L4, the intensity of the first-order diffracted light L6 at its inner beam portion is largely decreased, and secondary maxima (or side lobes) of the first-order diffracted light L6 at the converging spot S6 is undesirably increased. Therefore, the incident light L3 of which the far field pattern is distributed in the Gaussian distribution is radiated to the hologram lens 42 to increase the intensity of the transmitted light L4 without any increase of the second maxima. In detail, as shown in Fig. 18A, the incident light L3 distributed in not only a central portion of the Gaussian distribution but also a peripheral portion of the Gaussian distribution transmits through the hologram lens 42 and is refracted by the objective lens 27 because the diameter of the grating pattern P3 is equal to or larger than the aperture of the objective lens 27. Therefore, a numerical aperture NA of the objective lens 27 at a light source side for the incident light L3 becomes higher than that in the first embodiment, and a transmission efficiency of the hologram lens 42 is heightened. As a result, the intensity of the transmitted light L4 converged on the second information medium 25 can be increased, as shown in Fig. 18B. Also, because the intensity of the incident light L3 at the peripheral portion of the Gaussian distribution is low and because the diffraction efficiency of the hologram lens 42 is decreased toward the inner direction of the grating pattern 42A, the first-order diffracted light L6 is distributed in a gently-sloping shape as shown in Fig. 18C. Accordingly, secondary maxima of the first-order diffracted light L6 at the converging spot S5 can be suppressed.

Examples of the utilization of the imaging optical system 41 for various types of optical disks are described.

In cases where the image optical system 41 is utilized for an optical disk device in which pieces of information recorded in a thin type of high density optical disk and a thick type of compact disk are exclusively reproduced, the diffraction efficiency of the hologram lens 42 for the incident light L3 is set in a range from about 20 % to 70 %. In this case, the intensity of the transmitted light L4 converged on the compact disk is almost the same as that of the first-order diffracted light L6 converged on the high density optical disk. Therefore, the output power of the incident light L3 can be minimized.

Also, in cases where the image optical system 41 is utilized for an optical disk device in which pieces of information recorded in a thin type of high density optical disk are recorded or reproduced and pieces of information recorded in a thick type of optical disk are exclusively reproduced, the diffraction efficiency of the hologram lens 42 for the incident light L3 is set to a value equal to or higher than 55 %. In this case, even though a high intensity of the first-order diffracted light L6 is required to record a piece of information on the high density optical disk, the recording of the information can be reliably performed without increasing the intensity of the incident light L3 because the diffraction efficiency of the hologram lens 42 for changing the incident light L3 to the first-order diffracted light L6 is high. In other words, a utilization efficiency of the incident light L3 can be enhanced when a piece of information is recorded on the high density optical disk, so that the output power of the incident light L3 can be minimized. Also, because the diffraction efficiency of the hologram lens 42 is gradually decreased toward an inner direction of the pattern region 42A, the numerical aperture of the objective lens 27 for the first-order diffracted light L6 becomes substantially enlarged. Therefore, the intensity of the first-order diffracted light L6 can be enlarged to record or reproduce a piece of information on or from the high density optical disk.

In the third reference apparatus, the grating pattern P3 positioned in the pattern region 42A of the transparent substrate 28 is gradually changed toward the outer direction of the pattern region 42A from the step-wise shape shown in Fig. 12B to the step-wise shape shown in Fig. 12A through the step-wise shape shown in Fig. 12C while increasing the height H of the grating pattern P3. However, because the occurrence of unnecessary diffracted light such as minus first-order diffracted light can be effectively prevented in the middle portion of the transparent substrate 28 in which the grating pattern P3 is formed in the step-wise shape shown in Fig. 12C, it is preferred that the middle portion occupy a large part of the pattern region 42A of the hologram lens 42. In this case, the intensity sum of the transmitted light L4 and the first-order diffracted light L6 can be maximized, so that a utilization efficiency of the incident light L3 can be enhanced.

Also, because the first etching width W1 of the grating pattern P3 is gradually decreased toward the inner direction of the pattern region 42A, it is applicable that the grating pattern P3 formed in the step-wise shape shown in Fig. 12B be changed to a step-wise shape shown in Fig. 12D when the first width W1 is decreased to a value lower than about 1 μm. In this case, the grating pattern P3 formed in the step-wise shape shown in Fig. 12D can be easily made. In addition, in cases where a height H4 of the grating pattern P3 formed in the step-wise shape shown in Fig. 12D is moreover decreased toward the inner direction of the pattern region 42A, it is preferred that the grating pattern P3 be formed in a step-wise shape shown in Fig. 12E. In this case, a third etching width W3 is gradually decreased toward the inner direction of the pattern region 42A while decreasing a height H5 of the grating pattern P3. Therefore, the diffraction efficiency of the hologram lens 42 can be gradually decreased toward the inner direction of the pattern region

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42A without any manufacturing difficulty of the grating pattern P3.

In the first to third reference apparatus of the image optical systems 21, 31 and 41, the grating patterns P1, P2 and P3 of the hologram lenses 26, 32 and 42 are respectively formed on a front side of the transparent substrate 28 not facing the objective lens 27. Therefore, a beam of light reflected at the front side of the transparent substrate 28 does not adversely influence as stray light on the recording or reproduction of the information. In detail, because the reflected light is diffracted by the hologram lens, the reflected light is scattered. Also, even though the first-order diffracted light L5 or L6 is reflected at a reverse side of the transparent substrate 28, the diffracted light reflected is again diffracted by the hologram lens and is scattered. Therefore, the light reflected at the front or reverse side of the hologram lens does not adversely influence on the recording or reproduction of the information.

However, in cases where an anti-reflection film is coated on a front side of the hologram lens 28 at which the grating pattern is not formed, it is applicable that the grating patterns P1, P2 and P3 of the hologram lenses 26. 32 and 42 be respectively formed on a reverse side of the transparent substrate 28 facing the objective lens 27. In this case, because the first-order diffraction light L5, L6 is not refracted at the front side of the hologram lens 28, the design of the image optical systems 21, 31 and 41 can be simplified.

Also, in the first to third reference apparatus, the grating patterns P1, P2 and P3 of the hologram lenses 26, 32 and 42 are respectively formed in relief to produce a phase modulation type of hologram lens. However, as is described in Provisional Publication No. 189504/86 (S61-189504) and Provisional Publication No. 241735/88 (S63-24135), the phase modulation type of hologram lens can be produced by utilizing a liquid crystal cell. Also, the phase modulation type of hologram lens can be produced by utilizing a birefringece material such as lithium niobate. For example, the phase modulation type of hologram lens can be produced by proton-exchanging a surface part of a lithium niobate substrate.

(Fourth Reference Apparatus)

Also, in the first to third reference apparatus, the compound objective lens 29, 34 or 43 having two focal points is composed of the objective lens 27 and the hologram lens 26, 32 or 42. However, as a compound objective lens according to a fourth reference apparatus is shown in Fig. 19A, it is preferred that each of the hologram lenses 26, 32 and 42 and the objective lens 27 be unified with a packaging means 44 to form a compound objective lens 45 in which a relative position between each of the hologram lenses 26, 32 and 42 and the objective lens 27 is fixed. In this case, the transmitted light L4 and the first-order diffracted light L5, L6 can be easily converged on the first or second information medium 23, 25 by adjusting the position of the packing means 44 with an actuator. Also, as another compound objective lens according to a modified fourth reference apparatus is shown in Fig. 19B, it is preferred that each of the grating patterns P1, P2 and P3 be directly drawn on a curved side of the objective lens 27 facing a light source side to form a compound objective lens 46 in which each of the hologram lenses 26, 32 and 42 is integrally formed with the objective lens 27.

Accordingly, the central axis of the objective lens 27 can always agree with that of each of the hologram lenses 26, 32 and 42, so that abaxial aberrations of each of the hologram lenses 26, 32 and 42 such as a coma aberration and an astigmatic aberration occurring in the first-order diffracted light can be prevented in the fourth reference apparatus..

(Fifth Reference Apparatus)

Also, as a compound objective lens according to a fifth reference apparatus is shown in Fig. 20, it is referred that each of the grating patterns P1, P2 and P3 can be directly drawn on a side of the objective lens 27 facing the information medium 23 or 25 to form a compound objective lens 47 in which each of the hologram lenses 26, 32 and 42 is integrally formed with the objective lens 27. In this case, a curvature at the side of the objective lens 27 can be small or in a plane shape. Therefore, each of the grating patterns P1, P2 and P3 can be made at a low cost. Also, in cases where an aberration is caused by tilting the hologram lens from the optical axis, the aberration can be prevented by fixing the hologram lens and a light source of the incident light L3 on the same base.

(Sixth Reference Apparatus)

An optical head apparatus with one of the compound objective lenses 29, 29M, 34, 43, 45, 46 and 47 shown in the first to fifth reference apparatus is described with reference to Figs. 21 to 26 according to a sixth reference apparatus of the present invention. X, Y and Z coordinates shown in Figs. 21 to 26 are utilized in common.

Fig. 21 is a constitutional view of an optical head apparatus according to a sixth reference apparatus.

As shown in Fig. 21, an optical head apparatus 51 for recording or reproducing pieces of information on or from the information medium 23 or 25, comprises a light source 52 such as a semiconductor laser for radiating the incident

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light L3, a collimator lens 53 for collimating the incident light L3, a beam splitter 54 for transmitting the incident light L3 on an outgoing optical path and reflecting a beam of transmitted light L4R formed by reflecting the transmitted light L4 on the information medium 23 or 25 or a beam of diffracted light L5R (or L6R) formed by reflecting the diffracted light L5 (or L6) on the information medium 23 or 25 on an incoming optical path, the compound objective lens 29 (or 29M, 34, 43, 45, 46 or 47) composed of the hologram lens 26 (or 26M, 32, 33 or 42) and the objective lens 27, a converging lens 55 for converging the transmitted light L4R or the diffracted light L5R reflected by the beam splitter 54, a wavefront changing device 56 such as a hologram for changing a wavefront of the transmitted light L4R or the diffracted light L5R to form a plurality of converging spots of the transmitted light L4R or the diffracted light L5R, a photo detector 57 for detecting intensities of the converging spots of the transmitted light L4R or the diffracted light L5R of which the wavefront is changed by the wavefront changing device 56 to obtain an information signal recorded on the information medium 23 or 25 and servo signals such as a focus error signal and a tracking error signal, and an actuating unit 58 for moving the compound objective lens composed of the hologram lens 26 and the objective lens 27 according to the servo signals.

In the above configuration, a beam of incident light L3 radiated from the light source 52 is collimated in the collimator lens 53 and transmits through the beam splitter 54. Thereafter, a part of the incident light L3 transmits through the compound objective lens 29 without any diffraction, and a remaining part of the incident light L3 is diffracted.

Thereafter, in cases where a piece of information is recorded or reproduced on or from the first information medium 23, the transmitted light L4 is converged on the first information medium 23 to form the first converging spot S1. That is, the transmitted light L4 is incident on a rear surface of the first information medium 23, and the first converging spot S1 is formed on a front surface of the first information medium 23. Thereafter, a beam of transmitted light L4R reflected at the front surface of the first information medium 23 passes through the same optical path in the reverse direction. That is, a part of the transmitted light L4R again transmits through the compound objective lens 29 without any diffraction and is reflected by the beam splitter 54. In this case, the transmitted light L4R is collimated. Thereafter, the transmitted light L4R is converged by the converging lens 55, and the wavefront of a large part of the transmitted light L4R is changed to form a plurality of converging spots on the photo detector 57. Thereafter, the intensities of the converging spots of the transmitted light L4R are detected in the photo detector 57. Therefore, an information signal and servo signals such as a focus error signal and a tracking error signal are obtained. The actuating unit 58 are operated according to the servo signals to move the compound objective lens 29 at high speed, so that the transmitted light L4 is converged on the first information medium 23 in focus.

Also, in cases where a piece of information is recorded or reproduced on or from the second information medium 25, the diffracted light L5 is converged on the second information medium 25 to form the second converging spot S2. That is, the diffracted light L5 is incident on a rear surface of the second information medium 25, and the second converging spot S2 is formed on a front surface of the second information medium 25. Thereafter, a beam of diffracted light L5R reflected at the front surface of the second information medium 25 passes through the same optical path in the reverse direction. That is, a part of the diffracted light L5R is again diffracted by the hologram lens 26 and is reflected by the beam splitter 54. In this case, the diffracted light L5R is collimated. Thereafter, the diffracted light L5R is converged by the converging lens 55, and the wavefront of a large part of the diffracted light L5R is changed to form a plurality of converging spots on the photo detector 57. In this case, the diffracted light L5R incident on the converging lens 55 is collimated in the same manner as the transmitted light L4R incident on the converging lens 55, the converging spots of the diffracted light L5R are formed at the same positions as those of the transmitted light L4R. Thereafter, the intensities of the converging spots of the diffracted light L5R are detected in the photo detector 57. Therefore, an information signal and servo signals such as a focus error signal and a tracking error signal are obtained. The actuating unit 58 are operated according to the servo signals to move the compound objective lens 29 at high speed, so that the diffracted light L5 is converged on the second information medium 25 in focus.

In this case, because the transmitted light L4R again transmits through the compound objective lens without any diffraction and the diffracted light L5R is again diffracted by the hologram lens 26, the outgoing optical path agrees with the incoming optical path in a range between the information medium 23 or 25 and the beam splitter 54 even though the converging spot S1 differs from the converging spot S2. Therefore, a converging spot S7 on the photo detector 57 at which the light L4R or L5R not diffracted by the wavefront changing device 56 is converged relates to a radiation point of the light source 52 in a mirror image, so that the light L4R and L5R not diffracted by the wavefront changing device 56 are converged at the same converging point S7. In the same manner, the light L4R and L5R diffracted by the wavefront changing device 56 are converged at the same other converging points.

Accordingly, even though the compound objective lens has two focal points, the wavefront changing unit 56 and the photo detector 57 required to detect the intensity of the transmitted light L4R can be utilized to detect the intensity of the diffracted light L5R. Therefore, the number of parts required to manufacture the optical head apparatus 51 can be reduced, and a small sized optical head apparatus can be manufactured at a low cost and in light weight even though pieces of information are recorded or reproduced on or from an information medium by utilizing the optical head apparatus 51 regardless of whether the information medium is thick or thin.

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In cases where the hologram lens 26 (or 32, 33, 42) is integrally formed with the objective lens 27 as shown in Fig. 19A, 19B or 20, each of the compound objective lenses 45, 46 and 47 can be manufactured in light weight because the hologram lens 26 (or 32, 33, 42) is a plane type of optical device. For example, the hologram lens 26 (or 32, 33, 42) is less than several tens mg in weight. Therefore, the hologram lens 26 integrally formed with the objective lens 27 can be easily moved by the actuating unit 58.

Next, a detecting method of the servo signals is described. Fig. 22 is a plan view of the wavefront changing unit 56. Fig. 23 is an enlarged view of first-order diffracted light and transmitted light detected in the photo detector 57. As shown in Fig. 22, the wavefront changing unit 56 is partitioned into a diffracted light generating region 56a in which a grating pattern P4 is drawn and a pair of diffracted light generating regions 56b, 56c in which a pair of grating patterns P5, P6 are drawn. The light L4R or L5R incident on the diffracted light generating region 56a is diffracted to obtain a focus error signal. The light L4R or L5R incident on each of the diffracted light generating regions 56b, 56c is diffracted to obtain a tracking error signal.

Initially, a spot size detection method utilized to detect a focus error signal is described as an example of a detecting method of a focus error signal. The method is proposed in Japanese Patent Application No. 185722 of 1990. In short, in cases where the method is adopted, an allowable assembly error in an optical head apparatus can be remarkably enlarged, and the servo signal such as a focus error signal can be stably obtained to adjust the position of the compound objective lens even though the wavelength of the incident light L3 varies.

In detail, as shown in Fig. 23, the grating pattern P4 is designed to change the transmitted light L4R (or the diffracted light L5R) transmitting through the diffracted light generating region 56a of the wavefront changing unit 56 to a beam of first-order diffracted light L7 and a beam of minus first-order diffracted light L8. The diffracted light L7, L8 are expressed by two types of spherical waves having different curvatures. That is, interference fringes are produced by actually interfering a spherical wave having a focal point FP1 in the front of the photo detector 57 with another spherical wave diverging from the converging spot S7 according to a two-beam interferometric process, so that the grating pattern P4 agreeing with the interference fringes is formed. In other case, the interference fringes are calculated according to a computer generated hologram method. As a result, the transmitted light L4R (or the diffracted light L5R) transmitting through the diffracted light generating region 56a of the wavefront changing unit 56 is diffracted and changed to beams of conjugate diffracted light such as a beam of first-order diffracted light L7 and a beam of minus first-order diffracted light L8. The beam of first-order diffracted light L7 has the focal point FP1 at the front surface of the photo detector 57, and the beam of minus first-order diffracted light L8 has a focal point FP2 in the rear of the photo detector 57.

As shown in Fig. 24, the photo detector 57 comprises a sextant photo-detector 59 (or a six-division photo detector) in which six detecting sections SE1, SE2, SE3, SE4, SE5 and SE6 are provided. The intensity of the first-order diffracted light L7 is detected by each of the detecting sections SE1, SE2 and SE3 of the sextant photo-detector 59 and is changed to electric current signals SC1, SC2 and SC3. Also, the intensity of the minus first-order diffracted light L8 is detected by each of the detecting sections SE4, SE5 and SE6 of the sextant photo-detector 59 and is changed to electric current signals SC4, SC5 and SC6.

Fig. 25A and 25C respectively show a converging spot of the first-order diffracted light L7 radiated to the detecting sections SE1, SE2 and SE3 of the sextant photo-detector 59 and another converging spot of the minus first-order diffracted light L8 radiated to the detecting sections SE4, SE5 and SE6 of the sextant photo-detector 59 on condition that the objective lens 27 is defocused on the information medium 23 or 25. Fig. 25B shows a converging spot of the first-order diffracted light L7 radiated to the detecting sections SE1, SE2 and SE3 of the sextant photo-detector 59 and another converging spot of the minus first-order diffracted light L8 radiated to the detecting sections SE4, SE5 and SE6 of the sextant photo-detector 59 on condition that the objective lens 27 is just focused on the information medium 23 or 25.

As shown in Figs. 25A to 25C, in cases where the transmitted light L4 (or the diffracted light L5) is converged on the information medium 23 (or 25) on condition that the objective lens 27 is defocused on the information medium 23 (or 25), a converging spot S8 of the diffracted light L7 shown at the left side of Figs. 25A, 25C is formed on the sextant photo-detector 59, and another converging spot S9 of the diffracted light L8 shown at the right side of Fig. 25A or 25C is formed on the sextant photo-detector 59. In contrast, in cases where the transmitted light L4 (or the diffracted light L5) is converged on the information medium 23 (or 25) on condition that the objective lens 27 is just focused on the information medium 23 (or 25), a converging spot S8 of the diffracted light L7 shown at the left side of Fig. 25B is formed on the sextant photo-detector 59, and another converging spot S9 of the diffracted light L8 shown at the right side of Fig. 25B is formed on the sextant photo-detector 59. The intensity of the diffracted light L7 is detected in each of the detecting sections SE1, SE2 and SE3 of the sextant photo-detector 59 and is changed to electric current signals SC1, SC2, SC3. Also, the intensity of the diffracted light L8 is detected in the detecting sections SE4, SE5 and SE6 of the sextant photo-detector 59 and is changed to electric current signals SC4, SC5 and SC6. Thereafter, a focus error signal S_{fe} is obtained according to the spot size detection method by calculating an equation (5).

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$$S_{fe} = (SC1 + SC3 - SC2) - (SC4 + SC6 - SC5) \quad (5)$$

Thereafter, the position of the compound objective lens is moved in a direction along an optical axis at high speed so as to minimize the absolute value of the focus error signal S_{fe}.

In the spot size detection method, the diffracted light L7, L8 are expressed by two types of spherical waves having different curvatures to detect the focus error signal S_{fe}. However, two beams of diffracted light L7, L8 radiated to the photo detector 57 are not limited to the spherical waves. That is, because the change of the diffracted light L7, L8 in a Y-direction is detected by the photo detector 57 according to the spot size detection method, it is required that a one-dimensional focal point of the diffracted light L7 is positioned in the front of the photo detector 57 and a one-dimensional focal point of the diffracted light L8 is positioned in the rear of the photo detector 57. Therefore, it is applicable that diffracted light including astigmatic aberration be radiated to the photo detector 57.

In addition, an information signal S_{in} is obtained by adding all of the electric current signals according to an equation (6).

$$S_{in} = SC1 + SC2 + SC3 + SC4 + SC5 + SC6 \quad (6)$$

Because the information medium 23 or 25 is rotated at high speed, a patterned track pit radiated by the converging spots S8, S9 of the diffracted light L7,L8 is rapidly changed one after another, so that the intensity of the information signal S_{in} is changed. Therefore, the information stored in the information medium 23 or 25 can be reproduced according to the information signal S_{in}.

Next, the detection of a tracking error signal depending on a relative position between a converging spot and a patterned track pit on the information medium 23 or 25 is described.

The grating pattern P5 drawn in the diffracted light generating region 56b shown in Fig. 22 is designed to change the transmitted light L4R (or the diffracted light LSR) transmitting through the diffracted light generating region 56b of the wavefront changing unit 56 to a beam of first-order diffracted light L9 and a beam of minus first-order diffracted light L10. Also, the grating pattern P6 drawn in the diffracted light generating region 56c shown in Fig. 22 is designed to change the transmitted light L4R (or the diffracted light L5R) transmitting through the diffracted light generating region 56c of the wavefront changing unit 56 to a beam of first-order diffracted light L11 and a beam of minus first-order diffracted light L12.

As shown in Fig. 24, the photo detector 57 further comprises four tracking photo-detectors 60a to 60d for detecting intensities of the diffracted light L9 to L12. As shown in Fig. 26, the intensity of the diffracted light L9 is detected by the tracking photo-detector 60a and is changed to an electric current signal SC7, the intensity of the diffracted light L10 is detected by the tracking photo-detector 60d and is changed to an electric current signal SC10, the intensity of the diffracted light L11 is detected by the tracking photo-detector 60b and is changed to an electric current signal SC8, and the intensity of the diffracted light L12 is detected by the tracking photo-detector 60c and is changed to an electric current signal SC9. A tracking error signal S_{te} is calculated according to an equation (7).

$$S_{te} = SC7 - SC8 - SC9 + SC10 \quad (7)$$

Therefore, the asymmetry of the intensity distribution of the transmitted light L4R (or the diffracted light L5R) incident on the wavefront changing unit 56, which changes in dependence on the positional relation between the converging spot S1 (or S2) and a patterned track pit radiated by the light L4 or L5, is expressed by the tracking error signal S_{te}.

Thereafter, the objective lens 27 is moved in a radial direction so as to reduce a tracking error indicated by the tracking error signal S_{te}. The radial direction is defined as a direction perpendicular to both the optical axis and a series of patterned track pits. Therefore, the converging spot S1 (or S2) of the transmitted light L4 (or the diffracted light L5) on the information medium 23 (or 25) can be formed in the middle of the patterned track pit, so that the tracking error becomes zero.

Accordingly, focus and tracking servo characteristics can be stably obtained in the optical head apparatus 51. That is, because the wavefront changing unit 56 has a wavefront changing function, a focus error signal can be easily obtained. Also, because the diffracted light generating regions 56b, 56c are provided in the wavefront changing unit 56, a tracking error signal can be easily obtained. Therefore, the number of parts required to manufacture the optical head apparatus 51 can be reduced, and the number of manufacturing steps can be reduced. In addition, the optical head apparatus can be manufactured at a low cost and in light weight.

Also, because the compound objective lens having two focal points is utilized in the optical head apparatus 51,

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pieces of information can be reliably recorded or reproduced from an information medium by utilizing the optical head apparatus 51 regardless of whether the information medium is thick or thin.

(Seventh Reference Apparatus)

Next, an optical head apparatus in which servo signals such as a focus error signal and a tracking error signal are detected according to an astigmatic aberration method is described according to a seventh reference apparatus of the present invention.

Fig. 27 is a constitutional view of an optical head apparatus according to a seventh reference apparatus.

As shown in Fig. 27, an optical head apparatus 61 for recording or reproducing pieces of information on or from the information medium 23 or 25, comprises the light source 52, the collimator lens 53, the beam splitter 54, the compound objective lens 29 (or 29M, 34, 43, 45, 46 or 47) composed of the hologram lens 26 (or 26M, 32, 33 or 42) and the objective lens 27, the actuating unit 58, the converging lens 55, an astigmatic aberration generating unit 62 such as a plane parallel plate for generating an astigmatic aberration in the transmitted light L4R or the diffracted light L5R converged by the converging lens 55, and a photo detector 63 for detecting the intensity of the transmitted light L4R or the diffracted light L5R in which the astigmatic aberration is generated to obtain an information signal and servo signals such as a focus error signal and a tracking error signal.

The astigmatic aberration generating unit 62 is classified into one of the wavefront changing unit 56 because a wavefront of the transmitted light L4R or the diffracted light L5R is changed by the generating unit 62 to generate the astigmatic aberration in the light L4R or L5R. Also, a normal line of the unit 62 is tilted from an optical axis.

As shown in Fig. 28, the photo detector 63 comprises a quadrant photo-detector 64 in which four detecting sections SE7, SE8, SE9 and SE10 are provided.

In the above configuration, the transmitted light L4R (or the diffracted light L5R) reflected by the information medium 23 (or 25) is converged by the converging lens 55 in the same manner as in the sixth embodiment. Thereafter, the transmitted light L4R (or the diffracted light L5R) transmits through the astigmatic aberration generating unit 62 and is converged on the photo detector 57 to form a converging spot S10 on the detecting sections SE7, SE8, SE9 and SE10 of the quadrant photo-detector 64. In this case, because the transmitted light L4R (or the diffracted light L5R) converged by the converging lens 55 is a spherical wave, an astigmatic aberration is generated in the transmitted light L4R (or the diffracted light L5R) by the astigmatic aberration generating unit 62. Therefore, as shown in Figs. 29A to 29C, the shape of the converging spot S10 considerably changes depending on a distance between the compound objective lens 29 and the information medium 23 (or 25).

For example, in cases where the transmitted light L4 (or the diffracted light L5) is converged on the information medium 23 (or 25) on condition that the objective lens 27 is defocused on the information medium 23 (or 25), the converging spot S10 of the transmitted light L4R (or the diffracted light L5R) is formed on the quadrant photo-detector 64 as shown in Figs. 29A, 29C. In contrast, in cases where the transmitted light L4 (or the diffracted light L5) is converged on the information medium 23 (or 25) on condition that the objective lens 27 is just focused on the information medium 23 (or 25), the converging spot S10 of the transmitted light L4R (or the diffracted light L5R) is formed on the quadrant photo-detector 64 as shown in Fig. 25B.

The intensity of the transmitted light L4R (or the diffracted light L5R) is detected in the detecting sections SE7, SE8, SE9 and SE10 of the quadrant photo-detector 64 and is changed to electric current signals SC11, SC12, SC13 and SC14. Thereafter, a focus error signal S_{fe}, is obtained according to an astigmatic aberration method by calculating an equation (8).

$$S_{fe} = (SC11 + SC14) - (SC12 + SC13) \quad (8)$$

Thereafter, the position of the compound objective lens 29 is moved in a direction parallel to an optical axis at high speed so as to minimize the absolute value of the focus error signal S_{fe}.

Also, a tangential direction Dt agreeing with an extending direction of patterned recording pits and a radial direction Dr perpendicular to both the optical axis and the patterned recording pits are defined as shown in Fig. 29D. In this case, when the quadrant photo-detector 64 is directed as shown in Figs. 29A to 29C, a tracking error signal S_{te} is calculated according to an equation (9) by utilizing an intensity distribution change of the transmitted light L4R (or the diffracted light L5R) which depends on a positional relation between the converging spot S10 and a recording pit radiated by the light L4 or L5.

$$S_{te} = SC11 + SC13 - (SC12 + SC14) \quad (9)$$

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Thereafter, the objective lens 27 is moved in the radial direction so as to reduce a tracking error indicated by the tracking error signal S_{te}. Therefore, the converging spot S1, (or S2) of the transmitted light L4 (or the diffracted light L5) on the information medium 23 (or 25) can be formed in the middle of the recording pit, so that the tracking error becomes zero.

In other case, the tracking error signal S_{te} is obtained according to a phase difference method by utilizing the result calculated in the equation (8).

In addition, an information signal S_{in} is obtained by adding all of the electric current signals according to an equation (10).

$$S_{in} = SC11 + SC12 + SC13 + SC14 \quad (10)$$

Accordingly, focus and tracking servo characteristics can be stably obtained in the optical head apparatus 61. That is, because an astigmatic aberration is generated in the transmitted light L4R (or the diffracted light L5R) by the astigmatic aberration generating unit 62 made of a plane parallel plate, the servo signals such as a focus error signal and a tracking error signal can be easily obtained. Therefore, the number of parts required to manufacture the optical head apparatus 61 can be reduced, and the number of manufacturing steps can be reduced. In addition, the optical head apparatus 61 can be manufactured at a low cost and in light weight.

Also, because the compound objective lens having two focal points is utilized in the optical head apparatus 61, pieces of information can be reliably recorded or reproduced from an information medium by utilizing the optical head apparatus 61 regardless of whether the information medium is thick or thin.

In the seventh reference apparatus, the astigmatic aberration generating unit 62 formed out of the plane parallel plate is arranged between the converging lens 55 and the photo detector 63. However, as an optical head apparatus 65 is shown in Fig. 30, it is applicable that a cylindrical lens 66 integrally formed with the converging lens 55 be arranged in place of the plane parallel plate to generate an astigmatic aberration in the transmitted light L4R (or the diffracted light L5R). In this case, because the cylindrical lens 66 is integrally formed with the converging lens 55, the optical head apparatus can be moreover manufactured at low cost. In addition, as shown in Fig. 30, it is applicable that a normal line of the hologram lens 26 (or 32, 33, 42) be tilted from an optical axis passing through the center of the objective lens 27 by about one degree to prevent stray light reflected in a surface of the hologram lens 26 from being incident on the photo detector 57 or 63. Also, it is applicable that the hologram lens 26 (or 32, 33, 42) be coated with an anti-reflection coating to prevent the occurrence of stray light.

Also, as an optical head apparatus 67 is shown in Fig. 31, it is applicable that a polarized beam splitter 68 be arranged in place of the beam splitter 54 to perfectly transmit the incident light L3 and a 1/4-λ plate 69 be additionally placed between the hologram lens 26 (or 32, 33, 42) and the polarized beam splitter 68. In this case, because the incident light L3 transmits through the 1/4-λ plate 69 in an outgoing optical path and because the transmitted light L4R (or the diffracted light L5R) again transmits through the 1/4-λ plate 69 in an incoming optical path, the transmitted light L4R (or the diffracted light L5R) is perfectly reflected by the polarized beam splitter 68. Accordingly, a utilization efficiency of the incident light L3 can be enhanced. Also, a signal-noise ratio of each of the servo signals and the information signal can be enhanced.

Also, as an optical head apparatus 70 is shown in Fig. 32, it is applicable that the polarized beam splitter 68 be arranged in place of the beam splitter 54 to perfectly transmit the incident light L3 and the 1/4-λ plate 69 be additionally placed between the hologram lens 26 (or 32, 33, 42) and the objective lens 27. In this case, the transmitted light L4R (or the diffracted light L5R) is perfectly reflected by the polarized beam splitter 68 in the same manner as the optical head apparatus shown in Fig. 31. In addition, because stray light reflected from the hologram lens 26 (or 32, 33, 42) transmits through the polarized beam splitter 68, the stray light is not incident on the photo detector 63. Accordingly, a signal-noise ratio of each of the servo signals and the information signal can be moreover enhanced.

Also, as an optical head apparatus 71 is shown in Fig. 33, it is applicable that a wedge-like prism 72 for reshaping the incident light L3 radiated from the light source 52 be additionally placed between the collimator lens 53 and the polarized beam splitter 68. In this case, an elliptic wavefront of the incident light L3 is reshaped to a circular wavefront by the wedge-like prism 72. Accordingly, a utilization efficiency of the incident light L3 can be enhanced.

In the sixth and seventh reference apparatus, when the transmitted light L4 (that is, zero-order diffracted light L4) converged on the first information medium 23 is reflected toward the compound objective lens to reproduce a piece of information recorded on the first information medium 23, a part of the transmitted light L4R is diffracted in the hologram lens 26 (or 32, 33, 42) on the incoming optical path, so that the part of the transmitted light L4R is changed to a beam of first-order diffracted light L13. Therefore, the first-order diffracted light L13 diverges from the hologram lens 26, and a converging spot S11 of the diffracted light L13 is formed on the photo detector 57 or 63 in a relatively large size, as shown in Fig. 34. The size of the converging spot S11 is larger than those of the sextant photo-detector 59 and the

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quadrant photo-detector 64. Therefore, there is a drawback that a signal-noise ratio in the information signal deteriorates.

To solve the drawback, it is preferred that the photo detector 57 (or 63) further comprise an information photo-detector 73 surrounding the sextant photo-detector 59 (or the quadrant photo-detector 64). The size of the information photo-detector 73 is equal to or larger than a 1mm square. Therefore, in cases where the information signal is determined by the sum of the intensity of the transmitted light L4 detected in the sextant photo-detector 59 (or the quadrant photo-detector 64) and the intensity of the diffracted light L13 detected in the information photo-detector 73, the signal-noise ratio in the information signal can be enhanced. and frequency characteristics of the information signal can be enhanced.

(Eighth Reference Apparatus)

Next, a method of focusing performed in the optical head apparatuses 51, 61, 65, 67, 70 and 71 is described according to an eighth reference apparatus.

Fig. 35A graphically shows a change of the focus error signal obtained by detecting the intensity of the transmitted light L4 formed in the hologram lens 26, 32 or 33, the strength of the focus error signal depending on a distance between the objective lens 27 and the first information medium 23. Fig. 35B graphically shows a change of the focus error signal obtained by detecting the intensity of the diffracted light L5 formed in the hologram lens 26, 32 or 33, the strength of the focus error signal depending on a distance between the objective lens 27 and the second information medium 25.

The intensity of the transmitted light L4 is high because the numerical aperture of the objective lens 27 for the transmitted light L4 is large. Therefore, as shown in Fig. 35A, a change of a focus error signal FE1 obtained in cases where the objective lens 27 is almost focused on the first information medium 23 is considerably large as compared with a change of an unnecessary focus error signal FE2 obtained in cases where the objective lens 27 is defocused on the first information medium 23. In addition, in cases where the hologram lens 26, 32 or 33 is utilized in each of the optical head apparatuses 51, 61, 65, 67, 70 and 71, the unnecessary focus error signal FE2 is generated when the distance between the objective lens 27 and the first information medium 23 is larger than the focal length of the objective lens 27 for the transmitted light L4.

In contrast, the intensity of the diffracted light L5 is comparatively low because the numerical aperture of the objective lens 27 for the diffracted light L5 is comparatively small. Therefore, as shown in Fig. 35B, a change of a focus error signal FE3 obtained in cases where the objective lens 27 is almost focused on the second information medium 25 is almost the same as that of an unnecessary focus error signal FE4 obtained in cases where the objective lens 27 is defocused on the second information medium 25. In addition, in cases where the hologram lens 26, 32 or 33 is utilized in each of the optical head apparatuses 51, 61, 65, 67, 70 and 71, the unnecessary focus error signal FE4 is generated when the distance between the objective lens 27 and the second information medium 25 is smaller than the focal length of the objective lens 27 for the diffracted light L5.

Therefore, in cases where the focusing of the transmitted light L4 on the first information medium 23 is performed, the objective lens 27 placed far from the first information medium 23 is gradually brought near to the first information medium 23. Thereafter, when the strength of the focus error signal reaches a threshold value, a focus servo loop provided in the photo detector 57 or 63 is set to an operation condition, so that the objective lens 27 is set to be focused on the first information medium 23. Also, in cases where the focusing of the diffracted light L5 on the second information medium 25 is performed, the objective lens 27 placed far from the second information medium 25 is gradually brought near to the second information medium 25 in the same manner. Thereafter, when the strength of the focus error signal reaches a threshold value, a focus servo loop provided in the photo detector 57 or 63 is set to an operation condition, so that the objective lens 27 is set to be focused on the second information medium 25.

Accordingly, the inverse influence of the unnecessary focus error signal FE4 on the focusing of the diffracted light L5 can be prevented. Also, because the objective lens 27 placed far from the information medium 23 or 25 is gradually brought near to the information medium 23 or 25 regardless of whether the information medium is T1 or T2 in thickness, a focusing operation in each of the optical head apparatuses 51, 61, 65, 67, 70 and 71 with the hologram lens 26, 32 or 33 can be performed according to a common procedure by changing the threshold value or performing an auto gain control in which the focus error signal is normalized by detecting the total intensity of the transmitted light L4R or the diffracted light L5R. Therefore, a control circuit required to perform the focusing operation can be made at a low cost.

Fig. 36A graphically shows a change of the focus error signal obtained by detecting the intensity of the diffracted light L6 formed in the hologram lens 42, the strength of the focus error signal depending on a distance between the objective lens 27 and the first information medium 23. Fig. 36B graphically shows a change of the focus error signal obtained by detecting the intensity of the transmitted light L4 formed in the hologram lens 42, the strength of the focus error signal depending on a distance between the objective lens 27 and the second information medium 25.

As shown in Fig. 36A, a change of a focus error signal FE5 obtained in cases where the objective lens 27 is almost focused on the first information medium 23 is considerably large as compared with a change of an unnecessary focus

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error signal FE6 obtained in cases where the objective lens 27 is defocused on the first information medium 23. In addition, in cases where the hologram lens 42 is utilized in each of the optical head apparatuses 51, 61, 65, 67, 70 and 71, the unnecessary focus error signal FE6 is generated when the distance between the objective lens 27 and the first information medium 23 is smaller than the focal length of the objective lens 27 for the diffracted light L6.

In contrast, as shown in Fig. 36B, a change of a focus error signal FE7 obtained in cases where the objective lens 27 is almost focused on the second information medium 25 is almost the same as that of an unnecessary focus error signal FE8 obtained in cases where the objective lens 27 is defocused on the second information medium 25. In addition, in cases where the hologram lens 42 is utilized in each of the optical head apparatuses 51, 61, 65, 67, 70 and 71, the unnecessary focus error signal FE8 is generated when the distance between the objective lens 27 and the second information medium 25 is larger than the focal length of the objective lens 27 for the transmitted light L4.

Therefore, in cases where the focusing of the diffracted light L6 on the first information medium 23 is performed, the objective lens 27 placed near to the first information medium 23 is gradually moved away from the first information medium 23. Thereafter, when the strength of the focus error signal reaches a threshold value, a focus servo loop provided in the photo detector 57 or 63 is set to an operation condition, so that the objective lens 27 is set to be focused on the first information medium 23. Also, in cases where the focusing of the transmitted light L4 on the second information medium 25 is performed, the objective lens 27 placed near to the second information medium 25 is gradually moved away from the second information medium 25 in the same manner. Thereafter, when the strength of the focus error signal reaches a threshold value, a focus servo loop provided in the photo detector 57 or 63 is set to an operation condition, so that the objective lens 27 is set to be focused on the second information medium 25.

Accordingly, the inverse influence of the unnecessary focus error signal FE8 on the focusing of the transmitted light L4 can be prevented. Also, because the objective lens 27 placed near to the information medium 23 or 25 is gradually moved away from the information medium 23 or 25 regardless of whether the information medium is T1 or T2 in thickness, a focusing operation in each of the optical head apparatuses 51, 61, 65, 67, 70 and 71 with the hologram lens 42 can be performed according to a common procedure by changing the threshold value or performing the auto gain control. Therefore, a control circuit required to perform the focusing operation can be made at a low cost.

(Ninth Reference Apparatus)

An optical head apparatus with the compound objective lens 29, 34, 45, 46 or 47 in which the incident light L3 is efficiently utilized to obtain an information signal and servo signals is described with reference to Figs. 29, 37 according to a ninth reference apparatus.

Fig. 37 is a constitutional view of an optical head apparatus according to a ninth reference apparatus.

As shown in Fig. 37, an optical head apparatus 81 for recording or reproducing pieces of information on or from the information medium 23 or 25, comprises the light source 52, the collimator lens 53, the beam splitter 54, the compound objective lens the compound objective lens 29 (34, 45, 46 or 47) composed of the hologram lens 26 (or 32 or 33) and the objective lens 27, the actuating unit 58, the converging lens 55, a beam splitter 82 for transmitting a beam of diffracted light L5R or reflecting a beam of transmitted light L4R, the photo detector 63 for detecting the intensity of the diffracted light L5R transmitting through the beam splitter 82 to obtain servo signals and an information signal recorded on the second information medium 25, the wavefront changing device 56 such as a hologram for changing a wavefront of the transmitted light L4R reflected by the beam splitter 82, and the photo detector 57 for detecting the intensity of the transmitted light L4R to obtain servo signals and an information signal recorded on the first information medium 23. The beam splitter 82 is made of a plane parallel plate of which a normal line is tilted from an optical path, so that an astigmatic aberration is generated in the diffracted light LSR passing through the beam splitter 82. Also, a coating is applied on a surface of the plane parallel plate.

In the above configuration, the transmitted light L4 (or the diffracted light L5) are converged by the converging lens 27 in the same manner as in the sixth embodiment. Thereafter, in cases where a piece of information is recorded or reproduced on or from the first information medium 23, the transmitted light L4 is converged on the first information medium 23 to form the first converging spot S1. Thereafter, a beam of transmitted light L4R reflected by the first information medium 23 passes through the same optical path in the reverse direction. That is, a great part of the transmitted light L4R again transmits through the compound objective lens without any diffraction and is reflected by the beam splitter 54. Thereafter, the transmitted light L4R is converged by the converging lens 55, and a part of the transmitted light L4R is reflected by the beam splitter 82. Thereafter, the wavefront of a great part of the transmitted light L4R is changed by the wavefront changing unit 56, and the great part of the transmitted light L4R is converged on the photo detector 57 to form the converging spots S8, S9. Therefore, an information signal and servo signals such as a focus error signal and a tracking error signal are obtained in the same manner as in the sixth embodiment. Also, a remaining part of the transmitted light L4R not changed its wavefront is converged on the photo detector 57 to form the converging spot S7.

In contrast, in cases where a piece of information is recorded or reproduced on or from the second information

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medium 25, the diffracted light L5 is converged on the second information medium 25 to form the second converging spot S2. Thereafter, a beam of diffracted light L5R reflected by the second information medium 25 passes through the same optical path in the reverse direction, and a great part of the diffracted light L5R transmits through the hologram lens 26 without any diffraction. Therefore, the diffracted light L5R passes through the incoming optical path differing from the outgoing optical path. Thereafter, the diffracted light L5R is reflected by the beam splitter 54 and is converged by the converging lens 55. Thereafter, a part of the diffracted light L5R transmits through the beam splitter 82. In this case, an astigmatic aberration is generated in the diffracted light L5R. Thereafter, the diffracted light L5R is converged on the photo detector 63 to form a converging spot S12 of which the shape is the same as the converging spot S10 shown in Figs. 29A to 29C, and the intensity of the diffracted light L5R is detected in the photo detector 63. Therefore, an information signal and servo signals such as a focus error signal and a tracking error signal are obtained in the same manner as in the seventh embodiment.

In this case, though a remaining part of the transmitted light L4R transmits through the beam splitter 82, the remaining part of the transmitted light L4R is not converged at the converging spot S12 because the transmitted light L4R passes through the same optical path. Also, though a remaining part of the diffracted light L5R is reflected the beam splitter 82, the remaining part of the diffracted light L5R is not converged at the converging spot S7, S8 or S9 because the diffracted light L5R passes through the incoming optical path differing from the outgoing optical path.

In the ninth reference apparatus, because the diffracted light L5R transmits through the hologram lens 26 without any diffraction, the converging spot S12 formed on the photo detector 63 does not relate to a radiating point of the light source 52 in a mirror image, while the converging spot S7 formed on the photo detector 57 relates to the radiating point of the light source 52 in the mirror image. In other words, a focal point of the diffracted light L5R converged by the converging lens 55 differs from that of the transmitted light L4R converged by the converging lens 55. Therefore, the photo detector 57 for detecting the intensity of the transmitted light L4R and the photo detector 63 for detecting the intensity of the diffracted light L5R are required.

Accordingly, because the compound objective lens having two focal points is utilized in the optical head apparatus 81, pieces of information can be reliably recorded or reproduced on or from an information medium regardless of whether the information medium is thick or thin.

An example of the utilization of the optical head apparatus 81 for various types of optical disks is described.

In cases where the optical head apparatus 81 is utilized for an optical disk device in which pieces of information recorded in a thin type of high density optical disk 23 are recorded or reproduced and pieces of information recorded in a thick type of optical disk 25 are exclusively reproduced, the diffraction efficiency of the hologram lens 26, 32 or 33 in the compound objective lens 29, 34, 45, 46 or 47 for changing a beam of light to a beam of first-order diffracted light is set to a value equal to or lower than 30 %. Therefore, in cases where a piece of information recorded on the thick type of optical disk 25 is reproduced in the photo detector 63, a signal-noise ratio of each of the servo signals and the information signal obtained in the photo detector 63 can be enhanced because the diffracted light L5R transmitting through the hologram lens 26, 32 or 33 at a high transmission efficiency is utilized to obtain the servo signals and the information signal. In other words, a utilization efficiency of the incident light L3 can be enhanced when a piece of information recorded on the thick type of optical disk 25 is reproduced, so that the output power of the incident light L3 can be minimized. Also, even though a high intensity of the transmitted light L4 is required to record a piece of information on the high density optical disk 23, the recording of the information can be reliably performed without increasing the intensity of the incident light L3 because a transmission efficiency of the hologram lens 26, 32 or 33 for the incident light L3 is high. Also, in cases where a piece of information recorded on the high density optical disk 23 is reproduced in the photo detector 57, a signal-noise ratio of each signal obtained in the photo detector 57 can be enhanced because the transmission efficiency of the hologram lens 26, 32 or 33 for the light L3, L4R is high.

(Tenth Reference Apparatus)

An optical head apparatus with the compound objective lens 29, 34, 45, 46 or 47 in which the incident light L3 is efficiently utilized to obtain an information signal and servo signals is described with reference to Figs. 38, 39 according to a tenth reference apparatus. X1 and Y1 coordinates shown in Figs. 38, 39 are utilized in common.

Fig. 38 is a constitutional view of an optical head apparatus according to a tenth reference apparatus. Fig. 39 is a plan view of a beam splitter having a reflection type of hologram utilized in the optical head apparatus shown in Fig. 38.

As shown in Fig. 38, an optical head apparatus 91 for recording or reproducing pieces of information on or from the information medium 23 or 25, comprises the light source 52, the collimator lens 53, the beam splitter 54, the compound objective lens 29 (or 34, 45, 46 or 47) composed of the hologram lens 26 (or 32 or 33) and the objective lens 27, the actuating unit 58, the converging lens 55, a beam splitter 92 having a reflection type of hologram 93 for transmitting a large part of the transmitted light L4R or reflecting all of the diffracted light L5R incident on the hologram 93, the photo detector 63 for detecting the intensity of the transmitted light L4R transmitting through the beam splitter 92 to obtain servo signals and an information signal recorded in the first information medium 23, and the photo detector

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57 for detecting the intensity of the diffracted light L5R to obtain servo signals and an information signal recorded in the second information medium 25.

The beam splitter 92 is made of a plane parallel plate inclined to an optical path, so that an astigmatic aberration is generated in the transmitted light L4R passing through the beam splitter 92. Also, as shown in Fig. 39, the reflection type of hologram 93 is arranged at a center portion of the beam splitter 92, and a light transmitting region 92a is arranged at a peripheral portion of the beam splitter 92 to surround the hologram 93. Light incident on the light transmitting region 92a transmits without any diffraction. The hologram 92 is partitioned into a diffracted light generating region 93a in which a grating pattern P7 is drawn and a pair of diffracted light generating regions 93b, 93c in which a pair of grating patterns P8, P9 are drawn. The diffracted light L5R incident on the diffracted light generating region 93a is diffracted to obtain a focus error signal in the photo detector 57. The diffracted light L5R incident on each of the diffracted light generating regions 93b, 93c is diffracted to obtain a tracking error signal in the photo detector 57.

In the above configuration, the transmitted light L4 and the diffracted light L5 are converged by the converging lens 27 in the same manner as in the sixth reference apparatus. Thereafter in cases where a piece of information is recorded or reproduced on or from the first information medium 23, the transmitted light L4 is converged on the first information medium 23 to form the first converging spot S1. Thereafter, a beam of transmitted light L4R reflected by the first information medium 23 passes through the same optical path in the reverse direction. That is, a large part of the transmitted light L4R again transmits through the compound objective lens 29 without any diffraction and is reflected by the beam splitter 54. Thereafter, the transmitted light L4R is converged by the converging lens 55, and a large part of the transmitted light L4R transmits through the beam splitter 92. In this case, an astigmatic aberration is generated in the transmitted light L4R. Thereafter, the transmitted light L4R is converged on the photo detector 63 to form a converging spot S13 of which the shape is the same as the converging spot S10 shown in Figs. 29A to 29C. and the intensity of the transmitted light L4R is detected in the photo detector 63. Therefore, an information signal and servo signals such as a focus error signal and a tracking error signal are obtained in the same manner as in the seventh reference apparatus.

In contrast, in cases where a piece of information is recorded or reproduced on or from the second information medium 25, the diffracted light L5 is converged on the second information medium 25 to form the second converging spot S2. Thereafter, a beam of diffracted light L5R reflected by the second information medium 25 passes through the same optical path in the reverse direction, and a large part of the diffracted light L5R transmits through the hologram lens 26 without any diffraction. Therefore, the diffracted light L5R transmits on the incoming optical path differing from the outgoing optical path in the same manner as in the ninth embodiment. Thereafter, the diffracted light L5R is reflected by the beam splitter 54 and is converged by the converging lens 55 on the beam splitter 92 to form a converging spot on the reflection type of hologram 93 of the beam splitter 92. Therefore, all of the diffracted light L5R is diffracted and reflected by the hologram 93 to be converged on the photo detector 57. That is, the diffracted light L5R diffracted and reflected in the diffracted light generating region 93a of the hologram 93 is splitted into two beams and is converged on the detecting sections SE1 to SE6 of the sextant photo-detector 59 in the photo detector 57 in the same manner as in the sixth reference apparatus. Also, the diffracted light L5R diffracted and reflected in the diffracted light generating region 93b of the hologram 93 is splitted into two beams, and the intensity of the diffracted light L5R is detected in the tracking photo-detectors 60a and 60d. Also, the diffracted light L5R diffracted and reflected in the diffracted light generating region 93c of the hologram 93 is splitted into two beams, and the intensity of the diffracted light L5R is detected in the tracking photo-detectors 60b and 60c. Therefore, an information signal and servo signals such as a focus error signal and a tracking error signal are obtained in the same manner as in the sixth reference apparatus.

In the tenth reference apparatus, because the transmitted light L4R transmits through the hologram lens 26 without any diffraction, the converging spot S13 formed on the photo detector 63 does not relate to a radiating point of the light source 52 in a mirror image. Therefore, the photo detector 57 for detecting the intensity of the diffracted light L5R and the photo detector 63 for detecting the intensity of the transmitted light L4R are required.

Accordingly, because the compound objective lens having two focal points is utilized in the optical head apparatus 91, pieces of information can be reliably recorded or reproduced on or from an information medium regardless of whether the information medium is thick or thin.

Also, because all of the diffracted light L5R is completely diffracted and reflected by the hologram 93 of the beam splitter 92, the diffracted light L5R can be utilized at high efficiency. Therefore, a signal-noise ratio of the signals obtained in the photo detector 57 can be enhanced.

An example of the utilization of the optical head apparatus 91 for various types of optical disks is described.

In cases where the optical head apparatus 91 is utilized for an optical disk device in which pieces of information recorded in a thin type of high density optical disk 23 are recorded or reproduced and pieces of information recorded in a thick type of optical disk 25 are exclusively reproduced, the diffraction efficiency of the hologram lens 26, 32 or 33 in the compound objective lens 29, 34, 45, 46 or 47 for changing a beam of light to a beam of first-order diffracted light is set to a value equal to or lower than 30 %. Therefore, in cases where a piece of information recorded on the thick type of optical disk 25 is reproduced in the photo detector 57, a signal-noise ratio of each of the servo signals and the

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information signal obtained in the photo detector 57 can be enhanced because the diffracted light L5R transmitting through the hologram lens 26, 32 or 33 at a high transmission efficiency is utilized to obtain the servo signals and the information signal. In other words, a utilization efficiency of the incident light L3 can be enhanced when a piece of information recorded on the thick type of optical disk 25 is reproduced, so that the output power of the incident light L3 can be minimized. Also, even though a high intensity of the transmitted light L4 is required to record a piece of information on the high density optical disk 23, the recording of the information can be reliably performed without increasing the intensity of the incident light L3 because a transmission efficiency of the hologram lens 26, 32 or 33 for the incident light L3 is high. Also, in cases where a piece of information recorded on the high density optical disk 23 is reproduced in the photo detector 63, a signal-noise ratio of each signal obtained in the photo detector 63 can be enhanced because the transmission efficiency of the hologram lens 26, 32 or 33 for the light L3, L4R is high.

(Eleventh Reference Apparatus)

An optical head apparatus with the compound objective lens 29, 34, 45, 46 or 47 in which the incident light L3 is efficiently utilized to obtain an information signal and servo signals is described with reference to Figs. 40 to 42 according to an eleventh reference apparatus of the present invention. X1 and Y1 coordinates shown in Figs. 40, 41 are utilized in common, and X, Y and Z coordinates shown in Figs. 40, 42 are utilized in common.

Figs. 40A, 40B are respectively a constitutional view of an optical head apparatus according to an eleventh reference apparatus.

Fig. 41 is a plan view of a beam splitter having a reflection type of hologram utilized in the optical head apparatus shown in Fig. 38.

As shown in Figs. 40A, 40B, an optical head apparatus 101 for recording or reproducing pieces of information on or from the information medium 23 or 25, comprises the light source 52, the collimator lens 53, the beam splitter 54, the compound objective lens 29 (or 34, 45, 46 or 47) composed of the hologram lens 26 (or 32 or 33) and the objective lens 27, the actuating unit 58, the converging lens 55, a beam splitter 102 having a transmission type of hologram 103 for transmitting the transmitted light L4R converged on the first information medium 23 and the diffracted light L5R converged on the second information medium 25 and diffracting the transmitted light L4R which is converged on the second information medium 25 in defocus, a photo detector 104 for detecting the intensity of the transmitted light L4R converged on the first information medium 23 to obtain servo signals and an information signal recorded in the first information medium 23, detecting in defocus the intensity of the diffracted light L5R to obtain an information signal recorded in the second information medium 25, and detecting the intensity of the transmitted light L4R converged on the second information medium 25 in defocus to obtain a focus error signal.

The beam splitter 102 is made of a plane parallel plate inclined to an optical path, so that an astigmatic aberration is generated in the light L4R, L5R passing through the beam splitter 102. Also, as shown in Fig. 41, the transmission type of hologram 103 is arranged at a center portion of the beam splitter 102, and a light transmitting region 102a is arranged at a peripheral portion of the beam splitter 102 to surround the hologram 103. The transmitted light L4R incident on the light transmitting region 102a transmits without any diffraction. The hologram 102 is partitioned into diffracted light generating regions 103a, 103b alternately arranged to detect a focus error signal according to the spot size detection method described in the sixth reference apparatus. That is, a grating pattern P10 is drawn in each of the diffracted light generating regions 103a, and a converging spot is formed by the transmitted light L4R diffracted in the regions 103a. Also, a grating pattern P11 is drawn in each of the diffracted light generating regions 103b, and another converging spot is formed by the transmitted light L4R diffracted in the regions 103b.

The photo detector 104 comprises the sextant photo-detector 59 in which the detecting sections SE1, SE2, SE3, SE4, SE5 and SE6 are provided in the same manner as the photo detector 57.

In the above configuration, the transmitted light L4 and the diffracted light L5 are converged by the converging lens 27 in the same manner as in the sixth reference apparatus. Thereafter, in cases where a piece of information is recorded or reproduced on or from the first information medium 23, as shown in Fig. 40A, the transmitted light L4 is converged on the first information medium 23 to form the first converging spot S1. Thereafter, a beam of transmitted light L4R reflected by the first information medium 23 passes through the same optical path in the reverse direction. That is, the transmitted light L4R again transmits through the compound objective lens without any diffraction and is reflected by the beam splitter 54. Thereafter, the transmitted light L4R is converged by the converging lens 55, and a major part of the transmitted light L4R transmits through the beam splitter 103. In this case, an astigmatic aberration is generated in the transmitted light L4R. Thereafter, the transmitted light L4R is converged on the photo detector 104 to form a converging spot S14 of which the shape is the same as the converging spot S10 shown in Figs. 29A to 29C, and the intensity of the transmitted light L4R is detected in the photo detector 104. Therefore, an information signal and servo signals such as a focus error signal and a tracking error signal are obtained in the same manner as in the seventh embodiment. In this case, because the position of the photo detector 104 detecting the transmitted light L4R relates to a radiation point of the light source 52 in a mirror image, the transmitted light L4R is converged on the photo

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detector 104 just in focus.

In contrast, in cases where a piece of information is recorded or reproduced on or from the second information medium 25, as shown in Fig. 40B, the diffracted light L5 is converged on the second information medium 25 to form the second converging spot S2. Thereafter, a beam of diffracted light L5R reflected by the second information medium 25 passes through the same optical path in the reverse direction and transmits through the hologram lens 26 without any diffraction. Therefore, the diffracted light L5R transmits on the incoming optical path differing from the outgoing optical path in the same manner as in the ninth reference apparatus. Thereafter, the diffracted light L5R is reflected by the beam splitter 54 and is converged by the converging lens 55. Thereafter, a major part of the diffracted light L5R transmits through the beam splitter 102, and the diffracted light L5R is converged on the photo detector 57. In this case, an astigmatic aberration is generated in the diffracted light L5R. Also, because the diffracted light L5R is not diffracted by the hologram lens 26 on the incoming optical path, the position of the photo detector 104 detecting the diffracted light L5R does not relate to the radiation point of the light source 52 in the mirror image. Therefore, the diffracted light L5R is converged on the photo detector 104 in defocus. However, because the entire intensity of the diffracted light L5R converged in defocus is detected in the photo detector 104, an information signal is obtained in the same manner as in the seventh reference apparatus.

Also, the transmitted light L4 is converged on the second information medium 25 in defocus as shown in Fig. 40B. That is, the transmitted light L4 incident on the rear surface of the second information medium 25 is converged at the front surface of the second information medium 25. Thereafter, a beam of transmitted light L4R reflected at the front surface of the second information medium 25 again transmits through the compound objective lens without any diffraction and is reflected by the beam splitter 54. Thereafter, the transmitted light L4R is converged by the converging lens 55 on the beam splitter 102 to form a converging spot on the of hologram 103 of the beam splitter 102. Therefore, all of the transmitted light L4R is diffracted by the hologram 103 and is converged on the photo detector 104. That is, the transmitted light L4R diffracted in the diffracted light generating regions 103a of the hologram 103 is changed to a first spherical wave SW1 of which a focal point is placed at the front of the photo detector 104, and the transmitted light L4R diffracted in the diffracted light generating regions 103b of the hologram 103 is changed to a second spherical wave SW2 of which a focal point is placed at the rear of the photo detector 104. Thereafter, as shown in Figs. 42A to 42C, the first spherical wave SW1 is converged on the detecting sections SE1 to SE3 of the sextant photo-detector 59 in the photo detector 104 to form a converging spot S15A, and the second spherical wave SW2 is converged on the detecting sections SE4 to SE6 of the sextant photo-detector 59 to form a converging spot S15B. Because the regions 103a, 103b are divided into many pieces, the converging spots S15A, S15B are respectively divided into many pieces.

In cases where the diffracted light L5 is converged on the information medium 25 in defocus, the converging spots S15A, S15B of the transmitted light L4R shown in Figs. 42A, 42C are formed on the sextant photo-detector 59. In contrast, in cases where the diffracted light L5 is converged on the information medium 25 in focus, the converging spots S15A, S15B of the transmitted light L4R shown in Fig. 42B are formed on the sextant photo-detector 59. The intensity of the transmitted light L4R is detected in each of the detecting sections SE1 to SE6 of the sextant photo-detector 59 and is changed to electric current signals SC15 to SC20. Thereafter, a focus error signal S_{fe} is obtained according to the spot size detection method by calculating an equation (11).

$$S_{fe} = (SC15 + SC17 - SC16) - (SC18 + SC20 - SC19) \quad (11)$$

Thereafter, the position of the compound objective lens is moved in a direction along an optical axis at high speed so as to minimize the absolute value of the focus error signal S_{fe}. Therefore, the focus error signal is obtained in the same manner as in the sixth reference apparatus.

Accordingly, because the compound objective lens having two focal points is utilized in the optical head apparatus 101, pieces of information can be reliably recorded or reproduced on or from an information medium regardless of whether the information medium is thick or thin.

Also, because all of the transmitted light L4R reflected by the second information medium 25 is completely diffracted by the hologram 103 of the beam splitter 102 to detect the focus error signal, the transmitted light L4R can be utilized at high efficiency. Therefore, a signal-noise ratio of the focus error signal obtained in the photo detector 104 can be enhanced.

Also, the information signal and the servo signals can be obtained in the photo detector 104 regardless of whether the information medium 23 or 25 is thin or thick. Therefore, the number of parts required to manufacture the optical head apparatus 101 can be reduced, and a small sized optical head apparatus can be manufactured at a low cost and in light weight even though pieces of information are recorded or reproduced on or from an information medium by utilizing the optical head apparatus 101 regardless of whether the information medium is thick or thin.

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An example of the utilization of the optical head apparatus 101 for various types of optical disks is described.

In cases where the optical head apparatus 101 is utilized for an optical disk device in which pieces of information recorded in a thin type of high density optical disk 23 are recorded or reproduced and pieces of information recorded in a thick type of optical disk 25 are exclusively reproduced, the diffraction efficiency of the hologram lens 26, 32 or 33 in the compound objective lens 29, 34, 45, 46 or 47 is set to a value equal to or lower than 30 %. Therefore, in cases where a piece of information recorded on the thick type of optical disk 25 is reproduced in the photo detector 104, a signal-noise ratio of each of the servo signals and the information signal obtained in the photo detector 104 can be enhanced because the diffracted light L5R transmitting through the hologram lens 26, 32 or 33 at a high transmission efficiency is utilized to obtain the information signal. In other words, a utilization efficiency of the incident light L3 can be enhanced when a piece of information recorded on the thick type of optical disk 25 is reproduced, so that the output power of the incident light L3 can be minimized. Also, even though a high intensity of the transmitted light L4 is required to record a piece of information on the high density optical disk 23, the recording of the information can be reliably performed without increasing the intensity of the incident light L3 because a transmission efficiency of the hologram lens 26, 32 or 33 for the incident light L3 is high. Also, in cases where a piece of information recorded on the high density optical disk 23 is reproduced in the photo detector 63, a signal-noise ratio of each signal obtained in the photo detector 63 can be enhanced because the transmission efficiency of the hologram lens 26, 32 or 33 for the light L3, L4R is high.

(Twelfth Reference Apparatus)

An optical head apparatus with the compound objective lens 29M, 43, 45, 46 or 47 in which the incident light L3 is efficiently utilized to obtain an information signal and servo signals is described with reference to Fig. 43 according to a twelfth reference apparatus.

Fig. 43 is a constitutional view of an optical head apparatus according to a reference apparatus.

As shown in Fig. 43, an optical head apparatus 111 for recording or reproducing pieces of information on or from the information medium 23 or 25, comprises the light source 52, the collimator lens 53, the beam splitter 54, the compound objective lens 29M (or 43, 45, 46 or 47) composed of the hologram lens 42 (or 26M or 32) and the objective lens 27, the actuating unit 58, the converging lens 55, the beam splitter 82, the photo detector 63, the wavefront changing device 56, and the photo detector 57.

In the above configuration, a beam of incident light L3 radiated from the light source 52 is collimated in the collimator lens 53 and transmits through the beam splitter 54. Thereafter, a part of the incident light L3 transmits through the compound objective lens 29 without any diffraction, and a remaining part of the incident light L3 is diffracted.

Thereafter, in cases where a piece of information is recorded or reproduced on or from the first information medium 23, the diffracted light L6 is converged on the first information medium 23 to form the converging spot S5. That is, the diffracted light L6 is incident on the rear surface of the first information medium 23, and the converging spot S5 is formed on the front surface of the first information medium 23. Thereafter, a beam of diffracted light L6R reflected at the front surface of the first information medium 23 passes through the same optical path in the reverse direction, and a great part of the diffracted light L6R is again diffracted by the hologram lens 42. Therefore, the diffracted light L6R transmits on the incoming optical path agreeing with the outgoing optical path. Thereafter, the diffracted light L6R is reflected by the beam splitter 54 and is converged by the converging lens 55. Thereafter, a part of the diffracted light L6R transmits through the beam splitter 82. In this case, an astigmatic aberration is generated in the diffracted light L6R. Thereafter, the diffracted light L6R is converged on the photo detector 63 to form the converging spot S10 of which the shape is shown in Figs. 29A to 29C, and the intensity of the diffracted light L6R is detected in the photo detector 63. Therefore, an information signal and servo signals such as a focus error signal and a tracking error signal are obtained in the same manner as in the seventh reference apparatus.

In contrast, in cases where a piece of information is recorded or reproduced on or from the second information medium 25, the transmitted light L4 is converged on the second information medium 25 to form the converging spot S6. That is, the transmitted light L4 is incident on the rear surface of the second information medium 25, and the converging spot S6 is formed on the front surface of the second information medium 25. Thereafter, a beam of transmitted light L4R reflected at the front surface of the second information medium 25 passes through the same optical path in the reverse direction. That is, the transmitted light L4R is collimated by the objective lens 27 on the incoming optical path. Thereafter, a great part of the transmitted light L4R is diffracted by the hologram lens 42. Therefore, the transmitted light L4R transmits on the incoming optical path differing from the outgoing optical path. Thereafter, the transmitted light L4R is reflected by the beam splitter 54 and is converged by the converging lens 55. Thereafter, a part of the transmitted light L4R is reflected by the beam splitter 82. Thereafter, the wavefront of a great part of the transmitted light L4R is changed by the wavefront changing unit 56, and the great part of the transmitted light L4R is converged on the photo detector 57 to form converging spots S16, S17. Therefore, an information signal and servo signals such as a focus error signal and a tracking error signal are obtained in the same manner as in the sixth reference

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apparatus. Also, a remaining part of the transmitted light L4R not changed its wavefront by the wavefront changing unit 56 is converged on the photo detector 57 to form the converging spot S18.

In the twelfth reference apparatus because the transmitted light L4R is diffracted by the hologram lens 42 on the incoming optical path, the converging spot S18 formed on the photo detector 57 does not relate to a radiation point of the light source 52 in a mirror image, while the converging spot S10 formed on the photo detector 63 relates to the radiation point of the light source 52 in the mirror image. In other words, a focal point of the transmitted light L4R converged by the converging lens 55 differs from that of the diffracted light L6R converged by the converging lens 55. Therefore, the photo detector 57 for detecting the intensity of the transmitted light L4R and the photo detector 63 for detecting the intensity of the diffracted light L6R are required.

Accordingly, even though pieces of information are recorded or reproduced on or from an information medium, the information can be reliably recorded or reproduced on or from the information medium regardless of whether the information medium is thick or thin.

Also, because the diffracted light L6 formed in the hologram lens 42 converges before the diffracted light L6 is incident on the objective lens 27, the distance in an optical axis direction between the converging spots S5, S6 can be lengthened to about 1 mm. Therefore, even though the transmitted light L4 (or the diffracted light L6) is converged on the converging spot S6 (or S5) in focus to record or read a piece of information, the light L6 (or L4) is not converged on the converging spot S6 (or S5) in focus to reduce the intensity of the light L6 (or L4) at the converging spot S6 (or S5). Accordingly, no adverse influence is exerted on the recording or reproduction of the information

Also, because the hologram lens 42 functions as a convex lens for the first-order diffracted light L6, the occurrence of a chromatic aberration can be prevented in the optical head apparatus 111.

An example of the utilization of the optical head apparatus 111 for various types of optical disks is described.

In cases where the optical head apparatus 111 is utilized for an optical disk device in which pieces of information recorded in a thin type of high density optical disk 23 are recorded or reproduced and pieces of information recorded in a thick type of optical disk 25 are exclusively reproduced, the diffraction efficiency of the hologram lens 26M or 42 in the compound objective lens 29M, 43, 45, 46 or 47 for changing a beam of light to a beam of first-order diffracted light is set to a value equal to or higher than 55 %. Therefore, in cases where a piece of information recorded on the thick type of optical disk 25 is reproduced in the photo detector 57, a signal-noise ratio of each of the servo signals and the information signal obtained in the photo detector 57 can be enhanced because the transmitted light L4R diffracted by the hologram lens 26M or 42 at a high diffraction efficiency is utilized to obtain the servo signals and the information signal. In other words, a utilization efficiency of the incident light L3 can be enhanced when a piece of information recorded on the thick type of optical disk 25 is reproduced, so that the output power of the incident light L3 can be minimized. Also, even though a high intensity of the diffracted light L6 is required to record a piece of information on the high density optical disk 23, the recording of the information can be reliably performed without increasing the intensity of the incident light L3 because the diffraction efficiency of the hologram lens 26M or 42 for the incident light L3 and the diffracted light L6R is high. Also, in cases where a piece of information recorded on the high density optical disk 23 is reproduced in the photo detector 63, a signal-noise ratio of each signal obtained in the photo detector 63 can be enhanced because the diffraction efficiency of the hologram lens 26M or 42 for the light L3, L6R is high.

(Thirteenth Reference Apparatus)

An optical head apparatus with the compound objective lens 29M, 43, 45, 46 or 47 in which the incident light L3 is efficiently utilized to obtain an information signal and servo signals is described with reference to Fig. 44 according to a reference apparatus.

Fig. 44 is a constitutional view of an optical head apparatus according to a reference apparatus.

As shown in Fig. 44, an optical head apparatus 121 for recording or reproducing pieces of information on or from the information medium 23 or 25, comprises the light source 52, the collimator lens 53, the beam splitter 54, the compound objective lens 43 (or 29M, 45, 46 or 47) composed of the hologram lens 42 (or 26M or 32) and the objective lens 27, the actuating unit 58, the converging lens 55, the beam splitter 92 having the reflection type of hologram 93, the photo detector 63, and the photo detector 57.

In the above configuration, the transmitted light L4 and the diffracted light L6 are converged by the converging lens 27 in the same manner as in the twelfth reference apparatus. Thereafter, in cases where a piece of information is recorded or reproduced on or from the first information medium 23, the diffracted light L6 is converged on the first information medium 23 to form the converging spot S5. Thereafter, a beam of diffracted light L6R reflected by the first information medium 23 passes through the same optical path in the reverse direction, and a large part of the diffracted light L6R is diffracted by the hologram lens 42. Therefore, the diffracted light L6R transmits on the incoming optical path agreeing with the outgoing optical path in the same manner as in the twelfth embodiment. Thereafter, the diffracted light L6R is reflected by the beam splitter 54 and is converged by the converging lens 55 on the beam splitter 92 to

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form a converging spot on the reflection type of hologram 93 of the beam splitter 92. Therefore, all of the diffracted light L6R is diffracted and reflected by the hologram 93 to be converged on the photo detector 57 in the same manner as in the tenth embodiment. Therefore, an information signal and servo signals such as a focus error signal and a tracking error signal are obtained in the same manner as in the sixth reference apparatus.

In contrast, in cases where a piece of information is recorded or reproduced on or from the second information medium 25, the transmitted light L4 is converged on the second information medium 25 to form the converging spot S6. Thereafter, a beam of transmitted light L4R reflected by the second information medium 25 passes through the same optical path in the reverse direction. That is, a large part of the transmitted light L4R is collimated by the objective lens 27 on the incoming optical path. Thereafter, a great part of the transmitted light L4R is diffracted by the hologram lens 42. Therefore, the transmitted light L4R transmits on the incoming optical path differing from the outgoing optical path in the same manner as in the twelfth reference apparatus. Thereafter, the transmitted light L4R is reflected by the beam splitter 54 and is converged by the converging lens 55. Thereafter, a large part of the transmitted light L4R transmits through the beam splitter 92. In this case, an astigmatic aberration is generated in the transmitted light L4R. Thereafter, the transmitted light L4R is converged on the photo detector 63 to form a converging spot S19 of which the shape is the same as the converging spot S10 shown in Figs. 29A to 29C, and the intensity of the transmitted light L4R is detected in the photo detector 63. Therefore, an information signal and servo signals such as a focus error signal and a tracking error signal are obtained in the same manner as in the seventh reference apparatus.

In the thirteenth embodiment, because the transmitted light L4R is diffracted by the hologram lens 42, the converging spot S19 formed on the photo detector 63 does not relate to a radiation point of the light source 52 in a mirror image. Therefore, the photo detector 57 for detecting the intensity of the diffracted light L6R and the photo detector 63 for detecting the intensity of the transmitted light L4R are required.

Accordingly, because the compound objective lens having two focal points is utilized in the optical head apparatus 121, pieces of information can be reliably recorded or reproduced on or from an information medium regardless of whether the information medium is thick or thin.

Also, because the diffracted light L6 formed in the hologram lens 42 converges before the diffracted light L6 is incident on the objective lens 27, the distance in an optical axis direction between the converging spots S5, S6 can be lengthened to about 1 mm. Therefore, even though the transmitted light L4 (or the diffracted light L6) is converged on the converging spot S6 (or S5) in focus to record or read a piece of information, the light L6 (or L4) is not converged on the converging spot S6 (or S5) in focus to reduce the intensity of the light L6 (or L4) at the converging spot S6 (or S5). Accordingly, no adverse influence is exerted on the recording or reproduction of the information

Also, because the hologram lens 42 functions as a convex lens for the first-order diffracted light L6, the occurrence of a chromatic aberration can be prevented in the optical head apparatus 121.

An example of the utilization of the optical head apparatus 121 for various types of optical disks is described.

In cases where the optical head apparatus 121 is utilized for an optical disk device in which pieces of information recorded in a thin type of high density, optical disk 23 are recorded or reproduced and pieces of information recorded in a thick type of optical disk 25 are exclusively reproduced, the diffraction efficiency of the hologram lens 26M or 42 in the compound objective lens 29M, 43, 45, 46 or 47 for changing a beam of light to a beam of first-order diffracted light is set to a value equal to or higher than 70 %. Therefore, in cases where a piece of information recorded on the thick type of optical disk 25 is reproduced in the photo detector 57, a signal-noise ratio of each of the servo signals and the information signal obtained in the photo detector 57 can be enhanced because the transmitted light L4R diffracted by the hologram lens 26M or 42 at a high diffraction efficiency is utilized to obtain the servo signals and the information signal. In other words, a utilization efficiency of the incident light L3 can be enhanced when a piece of information recorded on the thick type of optical disk 25 is reproduced, so that the output power of the incident light L3 can be minimized. Also, even though a high intensity of the diffracted light L6 is required to record a piece of information on the high density optical disk 23, the recording of the information can be reliably performed without increasing the intensity of the incident light L3 because the diffraction efficiency of the hologram lens 26M or 42 for the incident light L3 and the diffracted light L6R is high. Also, in cases where a piece of information recorded on the high density optical disk 23 is reproduced in the photo detector 63, a signal-noise ratio of each signal obtained in the photo detector 63 can be enhanced because the diffraction efficiency of the hologram lens 26M or 42 for the light L3, L6R is high.

(Fourteenth Reference Apparatus)

An optical head apparatus in which noises included in an information signal are reduced is described with reference to Figs. 45, 46 according to a fourteenth reference apparatus.

Fig. 45 is a constitutional view of an optical head apparatus according to a fourteenth reference apparatus. Fig. 46 is a plan view of a hologram lens utilized in the optical head apparatus shown in Fig. 45.

As shown in Fig. 45, an optical head apparatus 131 for recording or reproducing pieces of information on or from

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the information medium 23 or 25, comprises the light source 52, a beam splitter 132 having a polarizing separation film 133 on its surface for reflecting the incident light L3 radiated from the light source 52 on an outgoing optical path and transmitting through the light L4R or L5R reflected on the information medium 23 or 25 on an incoming optical path, a collimator lens 134 for collimating the incident light L3 on the outgoing optical path and converging the light L4R or L5R on the incoming optical path, a hologram lens 135 for transmitting a part of the incident light L3 without any diffraction and diffracting a remaining part of the incident light L3, the 1/4-λ plate 69, the objective lens 27, the actuating unit 58, and a photo detector 136 for detecting the light transmitting through or diffracted by the hologram lens 135 on the incoming optical path.

As shown in Fig. 46, the hologram lens 135 is formed by drawing the grating pattern P1 in a central region 135a of the transparent substrate 28 and a grating pattern P12 in a peripheral region 135b surrounding the central region 135a. The grating pattern P12 is drawn in a non-concentric shape. Because the grating pattern P1 are drawn in the hologram lens 135, a compound objective lens 137 having two focal points is composed of the hologram lens 135 and the objective lens 27. Light passing through the peripheral region 135b of the hologram lens 135 is detected by the photo detector 136 to cancel noises included in an information signal. An optical axis of the optical head apparatus 131 passes through a central point of the grating pattern P1 and a central axis of the objective lens 27.

The photo detector 136 comprises the quadrant photo-detector 64 having the detecting sections SE7 to SE10 and a noise cancelling photo detector 138 for detecting the intensity of light passing through the peripheral region 135b of the hologram lens 135. Because the grating pattern P12 of the peripheral region 135b is drawn in the non-concentric shape, light diffracted in the peripheral region 135b is not converged on the detecting sections SE7 to SE10.

In the above configuration, the incident light L3 linearly polarized in a first direction is radiated from the light source 52 and is reflected by the beam splitter 132 because the polarizing separation film 133 functions as a mirror for the incident light L3 linearly polarized in the first direction. Therefore, the incident light L3 is directed in an upper direction and is collimated by the collimator lens 134. Thereafter, a part of the incident light L3 incident on the central region 135a of the hologram lens 135 transmits through the central region 135a without any diffraction to form the transmitted light L4, and a remaining part of the incident light L3 incident on the central region 135a of the hologram lens 135 is diffracted in the central region 135a to form the diffracted light L5. Also, a part of the incident light L3 incident on the peripheral region 135b of the hologram lens 135 transmits through the peripheral region 135b without any diffraction to form a beam of noise cancelling light L14. Thereafter, the light L4, L5 and L14 pass through the 1/4-λ plates so that the light L4, L5 and L14 linearly polarized in the first direction is changed to the light L4, L5 and L14 circularly polarized. Thereafter, the light L4, L5 and L14 are converged by the converging lens 27.

Thereafter, in cases where a piece of information is recorded or reproduced on or from the first information medium 23 (or the second information medium 25), the transmitted light L4 (or the diffracted light L5) is converged on the information medium 23 (or 25) to form the converging spot S1 (or S2). Thereafter, a beam of transmitted light L4R (or a beam of diffracted light L5R) reflected by the information medium 23 (or 25) passes through the same optical path in the reverse direction. That is, the transmitted light L4R (or the diffracted light L5R) is circularly polarized in reverse and again passes through the converging lens 27 and the 1/4-λ plate 69. Therefore, the light L4R (or L5R) is linearly polarized in a second direction perpendicular to the first direction. Thereafter, a part of the transmitted light L4R transmits through the central region 135a of the hologram lens 135 without any diffraction, or a part of the diffracted light L5R is again diffracted in the central region 135a. Thereafter, the transmitted light L4R (or the diffracted light L5R) is converged by the collimator lens 134 and passes through the beam splitter 132 without any reflection because the polarizing separation film 133 functions as a transparent plate for the light L4R (or L5R) linearly polarized in the second direction. In this case, an astigmatic aberration is generated in the transmitted light L4R (or the diffracted light L5R) in the same manner as in the seventh reference apparatus. Thereafter, the transmitted light L4R (or the diffracted light L5R) is incident on the detecting sections SE7 to SE10 of the photo detector 136 to form a converging spot S20 of which the shape is the same as the converging spot S10 shown in Figs. 29A to 29C. The intensity of the transmitted light L4R (or the diffracted light L5R) is changed to electric current signals SC21 to SC24 in the detecting sections SE7 to SE10. Therefore, servo signals such as a focus error signal and a tracking error signal are obtained in the same manner as in the seventh reference apparatus, so that the position of the compound objective lens 137 is adjusted to converge the transmitted light L4 (or the diffracted light L5) on the information medium 23 (or 25) in focus. Also, an information signal expressing a piece of information recorded on the information medium 23 (or 25) is obtained according to an equation (12).

$$S_{in} = SC21 + SC22 + SC23 + SC24 \quad (12)$$

Also, the noise cancelling light L14 is converged on the information medium 23 to form a converging spot surrounding the converging spot S1. Thereafter, a beam of noise cancelling light L14R reflected by the first information

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medium 23 passes through the same optical path in the reverse direction. That is, the noise cancelling light L14R again passes through the converging lens 27 and the 1/4-λ plate 69, and a part of the noise cancelling light L14R is diffracted and converged in the peripheral region 135b of the hologram lens 135 and is incident on the noise cancelling photo detector 138. In the photo detector 138, an output signal SC25 is generated according to the intensity of the noise cancelling light L14R. Thereafter, a noise cancelled information signal S_{nc} expressing a piece of information recorded on the first information medium 23 is obtained by adding all of the signals according to an equation (13):

$$S_{nc} = (SC21 + SC22 + SC23 + SC24) + R \times SC25 \quad (13),$$

where the symbol R is a weighting factor.

In this case, because the term R × SC25 is added to obtain the information signal S_{nc}, inverse influence of noises included in the term (SC21 + SC22 + SC23 + SC24) on the noise cancelled information signal S_{nc} can be reduced. The reason is described.

As is well known (for example, Japanese Patent Gazette No. 22452 of 1990 laid open to public inspection on July 23, 1985 under Provisional Publication No. 138748 of 1985 and Published Unexamined Patent Application No. 131245 of 1986), signals expressing pieces of information recorded on an optical disk shifts to a higher frequency as the density of the information recorded becomes high. Also, the amplitude of a signal having a high frequency becomes low as compared with that of a signal having a low frequency in cases where the signals are produced according to light passing through a central region of a hologram lens. In contrast, the amplitude of a signal having a high frequency is emphasized in cases where the signal is produced according to light passing through a peripheral region of the hologram lens. Therefore, in cases where the information signal S_{nc} is obtained according to the equation (13), high frequency components included in the information signal S_{nc} is emphasized, and low frequency noise components included in the term (SC21 + SC22 + SC23 + SC24) are comparatively reduced. As a result, a signal-noise ratio in the information signal S_{nc} can be enhanced.

Accordingly, because the compound objective lens having two focal points is utilized in the optical head apparatus 131, pieces of information can be reliably recorded or reproduced or or from an information medium regardless of whether the information medium is thick or thin.

Also, even though pieces of information are densely recorded in a thin type of high density optical disk represented by the first information medium 23, the information signal S_{nc} can be reliably reproduced at a high signal-noise ratio.

Also, because the intensity of the light L4R or L5R incident on the detecting sections SE7 to SE10 of the photo detector 136 is reduced by converging the noise cancelling light L14R on the photo detector 138, a positioning accuracy of the photo detector 136 can be coarsely lowered to 1/100.

Also, in cases where the grating pattern P12 of the peripheral region 135b functions as a lens for the incident light L3 diffracted in the peripheral region 135b, unnecessary diffracted light generated in the peripheral region 135b on the outgoing optical path forms a comparatively large converging spot in defocus on the first information medium 23. Therefore, pieces of information recorded on the first information medium 23 are read by the unnecessary diffracted light, and the information are treated as a piece of averaged information in the photo detector 136 even though the unnecessary diffracted light is incident on the photo detector 136. Accordingly, the information read by the unnecessary diffracted light does not adversely influence on the information signal S_{nc} as a noise.

Also, in cases where a transmission efficiency of the peripheral region 135b of the hologram lens 135 is set to agree with another transmission efficiency of the central region 135a, secondary maxima (or side lobes) occurring around the converging spot S1 can be lowered as compared with the first embodiment. Accordingly, a signal-noise ratio in the information signal S_{nc} can be enhanced.

(Fifteenth Reference Apparatus)

An optical head apparatus in which noises included in an information signal are reduced is described with reference to Figs. 47 to 49 according to a fifteenth reference apparatus of the present invention.

Fig. 47 is a constitutional view of an optical head apparatus according to a fifteenth reference apparatus. Fig. 48 is a plan view of a hologram lens utilized in the optical head apparatus shown in Fig. 47.

As shown in Fig. 47, an optical head apparatus 141 for recording or reproducing pieces of information on or from the information medium 23 or 25, comprises the light source 52, the beam splitter 82, the collimator lens 134, a hologram lens 142 for transmitting a part of the incident light L3 without any diffraction and diffracting a remaining part of the incident light L3, the objective lens 27, the actuating unit 58, and a photo detector 143 for detecting the light transmitting through or diffracted by the hologram lens 142 on the incoming optical path.

As shown in Fig. 48, the hologram lens 142 is partitioned into a central region 142a in which the grating pattern

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P1 is drawn, a pair of side peripheral regions 142b, 142c in which grating patterns P13, P14 are drawn to cancel noises included in an information signal, and a pair of no-designed regions 142d, 142e in which no grating pattern is drawn not to reduce the intensity of light. Because the grating pattern P1 are drawn in the hologram lens 135, a compound objective lens 144 having two focal points is composed of the hologram lens 142 and the objective lens 27. An optical axis of the optical head apparatus 141 passes through a central point of the grating pattern P1 and a central axis of the objective lens 27.

The photo detector 143 comprises the quadrant photo-detector 64 having the detecting sections SE7 to SE10, a pair of noise cancelling photo detector 138a, 138b for detecting the intensity of light passing through the peripheral region 142b, 142c of the hologram lens 142.

In the above configuration, the transmitted light L4 (or the diffracted light L5) generated in the central region 142a of the hologram lens 142 is converged on the first information medium 23 (or the second information medium 25) in an outgoing optical path to form the converging spot S1 (or S2). Thereafter, the transmitted light L4R (or the diffracted light L5R) passes through the same optical path in the reverse direction. That is, the transmitted light L4R (or the diffracted light L5R) again passes through the converging lens 27, and a part of the transmitted light L4R transmits through the central region 142a of the hologram lens 142 without any diffraction or a part of the diffracted light L5R is again diffracted in the central region 142a. Thereafter, the transmitted light L4R (or the diffracted light L5R) is converged by the collimator lens 134 and passes through the beam splitter 82. In this case, an astigmatic aberration is generated in the transmitted light L4R (or the diffracted light L5R) in the same manner as in the seventh reference apparatus. Thereafter, the transmitted light L4R (or the diffracted light L5R) is incident on the detecting sections SE7 to SE10 of the photo detector 143 to form a converging spot S21 of which the shape is the same as the converging spot S10 shown in Figs. 29A to 29C. The intensity of the transmitted light L4R. (or the diffracted light L5R) is changed to electric current signals SC26 to SC29 in the detecting sections SE7 to SE10. Therefore, servo signals such as a focus error signal and a tracking error signal are obtained in the same manner as in the seventh reference apparatus, so that the position of the compound objective lens 144 is adjusted to converge the transmitted light L4 (or the diffracted light L5) on the information medium 23 (or 25) in focus. Also, an information signal recorded on the second information medium 25 is obtained according to an equation (14).

$$S_{in} = SC26 + SC27 + SC28 + SC29 \quad (14)$$

Also, a part of the incident light L3 incident on the peripheral region 142b of the hologram lens 142 transmits through the peripheral region 142b without any diffraction to form a beam of noise cancelling light L15, and a part of the incident light L3 incident on the peripheral region 142c of the hologram lens 142 transmits through the peripheral region 142c without any diffraction to form a beam of noise cancelling light L16. Thereafter, the noise cancelling light L15, L16 are converged on the information medium 23 to form a converging spot surrounding the converging spot S1. Thereafter, beams of noise cancelling light L15R, L16R reflected by the first information medium 23 passes through the same optical path in the reverse direction. That is, the noise cancelling light L15R, L16R again passes through the converging lens 27. A part of the noise cancelling light L15R is diffracted and converged in the peripheral region 142b of the hologram lens 142 and is incident on the noise cancelling photo detector 138a, and a part of the noise cancelling light L16R is diffracted and converged in the peripheral region 142c of the hologram lens 142 and is incident on the noise cancelling photo detector 138b. In the photo detector 138a, an output signal SC30 is generated according to the intensity of the noise cancelling light L15R. Also, an output signal SC31 is generated according to the intensity of the noise cancelling light L16R in the photo detector 138b. Thereafter, a noise cancelled information signal S_{nc} expressing the information recorded on the first information medium 23 is obtained by adding all of the signals according to an equation (15):

$$S_{nc} = (SC26+SC27+SC28+SC29) + R\times(SC30+SC31) \quad (15),$$

where the symbol R is a weighting factor.

Accordingly, because the compound objective lens having two focal points is utilized in the optical head apparatus 141, pieces of information can be reliably recorded or reproduced from an information medium regardless of whether the information medium is thick or thin.

Also, a signal-noise ratio in the information signal S_{nc} can be enhanced in the same manner as in the fourteenth reference apparatus.

Also, even though pieces of information are densely recorded in a thin type of high density optical disk represented by the first information medium 23, the information signal S_{nc} can be reliably reproduced at a high signal-noise ratio.

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Also, because the intensity of the light L4R or L5R incident on the detecting sections SE7 to SE10 of the photo detector 143 is reduced by converging the noise cancelling light L15R, L16R on the photo detectors 138a, 138b, a positioning accuracy of the photo detector 143 can be coarsely lowered to 1/100.

Also, in cases where the grating patterns P13, P14 of the peripheral regions 142b, 142c functions as a lens for the incident light L3 diffracted in the peripheral region 142b, 142c, unnecessary diffracted light generated by diffracting the incident light L3 in the peripheral regions 142b, 142c on the outgoing optical path forms a comparatively large converging spot in defocus on the first information medium 23. Also, an numerical number of each of the peripheral regions 142b, 142c is lowered as compared with that of the region 135b in the fourteenth embodiment because the hologram lens 142 are partitioned into many fields. Therefore, the size of the converging spot of the unnecessary diffracted light formed in defocus on the first information medium 23 becomes larger than that in the fourteenth reference apparatus. As a result, more pieces of information recorded on the first information medium 23 are read by the unnecessary diffracted light, and the information are treated as a piece of averaged information in the photo detector 143 even though the unnecessary diffracted light is incident on the photo detector 143. Accordingly, the information read by the unnecessary diffracted light is moreover averaged, and the averaged information does not adversely influence on the information signal S_{nc} as a noise.

Also, as shown in Figs. 49A, 49B, the unnecessary diffracted light can be prevented from being incident on the photo detector 64 in which each of the detecting sections SE7 to SE10 has SL0 square in size. In detail, in cases where light generated in the peripheral region 142c on the outgoing optical path is again diffracted in the peripheral region 142b to form a beam of unnecessary diffracted light Lu_1, the light Lu_1 is converged on a first position PT1 spaced SP1 (SP1 > SL0) from the center of the photo detector 64. In cases where light generated in the peripheral region 142b on the outgoing optical path is again diffracted in the peripheral region 142c to form a beam of unnecessary diffracted light Lu_2, the light Lu_2 is converged on a second position PT2 spaced SP2 (SP2 > SL0) from the center of the photo detector 64. In cases where light generated in the peripheral regions 142b, 142c on the outgoing optical path are again diffracted in the same peripheral regions 142b, 142c to form beams of unnecessary diffracted light Lu_3, Lu_4, the light Lu_3, Lu_4 are converged on third and fourth position PT3, PT4 spaced SP3 (SP3 > SL0), SP4 (SP4 > SL0) from the center of the photo detector 64. Accordingly, the adverse influence of the unnecessary diffracted light Lu_1 to Lu_4 can be prevented.

In cases where the light source 52 is formed of a semiconductor laser, a far field pattern of the incident light L3 incident on the hologram lens 142 is distributed in the Gaussian distribution as shown in Fig. 13A, and a cross-sectional beam profile of the incident light L3 distributed in the Gaussian distribution is in an elliptic shape. That is, a beam divergent angle (or a full angle at half maximum) of the incident light L3 in a perpendicular direction is larger than that in a horizontal direction. In this apparatus, the perpendicular direction of the incident light L3 is directed in an X2 direction shown in Fig. 48, and the horizontal direction of the incident light L3 is directed in a Y2 direction shown in Fig. 48. In this case, because a transmission efficiency of the regions 142b, 142c for the incident light L3 is smaller than that of the regions 142d, 142e, the intensity of the incident light L3 transmitting through the hologram lens 142 without any diffraction is largely reduced in the perpendicular direction as compared with that in the horizontal direction. Therefore, the cross-sectional beam profile of the incident light L3 is corrected to a circular shape in the hologram lens 142. That is, the converging spot S1 formed on the first information medium 23 is corrected to the circular shape. Accordingly, secondary maxima (or side lobes) occurring around the converging spot S1 can be lowered, and a signal-noise ratio of the information signal S_{nc} can be enhanced.

In the fifteenth reference apparatus, the noise cancelled information signal S_{nc} is obtained according to the equation (15). However, it is preferred that the noise cancelled information signal S_{nc} be obtained according to the equation (16):

$$S_{nc} = (SC26+SC27+SC28+SC29) + (R1 \times SC30 + R2 \times SC31) \quad (16),$$

where the symbols R1,R2 are weighting factors. In this case, the noises included in the information can be moreover reduced.

(Sixteenth Reference Apparatus)

An optical head apparatus manufactured in a small size and stably operated is described with reference to Figs. 50, 51 according to a sixteenth reference apparatus.

Fig. 50 is a constitutional view of an optical head apparatus according to a sixteenth reference apparatus. Fig. 51 is a diagonal view of a light source and photo detectors utilized in the optical head apparatus shown in Fig. 50.

As shown in Fig. 50, an optical head apparatus 151 for recording or reproducing pieces of information on or from the information medium 23 or 25, comprises the light source 52 for radiating the incident light L3 linearly polarized in

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a non-diffracting direction parallel to an X3 axis, an holographic element 152 for transmitting through the incident light L3 without any diffraction on an outgoing optical path and diffracting the transmitted light L4R or the diffracted light L5R linearly polarized in a diffracting direction parallel to a Y3 axis on an incoming optical path, the collimator lens 53, the 1/4-λ plate 69, the hologram lens 26 (or 26M, 32, 33, 42, 135 or 142), the objective lens 27, the actuating unit 58, and a photo detector 153 for detecting the intensity of the light L4R or L5R diffracted by the holographic element 152.

As shown in Fig. 51, the light source 52 and the photo detector 153 are located on a substrate 154 to precisely fix a relative position between the light source 52 and the photo detector 153. The photo detector 153 comprises the sextant photo-detector 59 having the detecting sections SE1 to SE6 and the tracking photo-detectors 60a to 60d. Also, a mirror element 155 is located on the substrate 154 to direct the incident light L3 radiated from the light source 52 in a Z3 direction.

The holographic element 152 is produced by proton-exchanging surface parts of a lithium niobate substrate or by utilizing a liquid crystal cell, as is described in Provisional Publication No. 189504/86 (S61-189504) and Provisional Publication No. 241735/88 (S63-241735). Therefore, light linearly polarized in a non-diffracting direction parallel to an X3 axis transmits through the holographic element 152 without any diffraction. In contrast, light linearly polarized in a diffracting direction parallel to a Y3 axis which is perpendicular to the X3 axis is diffracted by the holographic element 152.

In the above configuration, the incident light L3 linearly polarized in a non-diffracting direction parallel to an X3 axis is radiated from the light source 52 and transmits through the holographic element 152 without any diffraction. Thereafter, the incident light L3 is collimated by the collimator lens 53, and the incident light L3 linearly polarized is changed to the incident light L3 circularly polarized by the 1/4-λ plate 69. Thereafter, a part of the incident light L3 transmits through the hologram lens 26 without any diffraction to form the transmitted light L4, and a remaining part of the incident light L3 is diffracted by the hologram lens 26 to form the diffracted light L5. Thereafter, the light L4, L5 are converged by the objective lens 27, and the converging spot S1 of the transmitted light L4 (or the converging spot S2 of the diffracted light L5) is formed on the first information medium 23 (or the second information medium 25). When the light L4 or L5 is reflected by the information medium 23 (or 25) and is changed to the light L4R (or L5R), a rotational direction of the circular polarization in the light L4 is reversed. Therefore, the light L4R (or L5R) having the reversed circular polarization passes through the same optical path in the opposite direction. That is, the transmitted light L4R (or the diffracted light L5R) again passes through the converging lens 27, and a part of the transmitted light L4R transmits through the hologram lens 142 without any diffraction or a part of the diffracted light L5R is again diffracted by the hologram lens 142. Thereafter, the transmitted light L4R (or the diffracted light L5R) circularly polarized in reverse is changed to the light L4R (or L5R) linearly polarized in a diffracting direction parallel to a Y3 axis by the 1/4-λ plate 69. Thereafter, the light L4R (or L5R) is converged by the collimator lens 53 and is diffracted by the holographic element 152 to form a plurality of converging spots on the photo detectors 153. Therefore, an information signal expressing a piece of information recorded on the information medium 23 (or 25) and servo signals such as a focus error signal and a tracking error signal are obtained in the photo detector 153 in the same manner as in the sixth reference apparatus.

Accordingly, because the compound objective lens having two focal points is utilized in the optical head apparatus 151, pieces of information can be reliably recorded or reproduced or or from an information medium regardless of whether the information medium is thick or thin.

Also, because all of the incident light L3 transmits through the holographic element 152 on the outgoing optical path and because all of the light L4R or L5R is diffracted by the holographic element 152 on the incoming optical path, a utilization efficiency of the incident light L3 can be enhanced. Therefore, even though a radiation intensity of the incident light L3 in the light source 52 is low, the information signal and the servo signals having a high signal-noise ratio can be reliably obtained.

Also, because no beam splitter is utilized in the optical head apparatus 151, the optical head apparatus 151 can be manufactured at a small size, in a light weight, and at a low cost.

Also, because optical parts of the optical head apparatus 151 are located along its optical axis, the optical head apparatus 151 stably operated can be obtained even though a circumstance temperature largely varies and the apparatus is operated for a long time.

Also, because the light L4R or L5R transmitting through the holographic element 152 without any diffraction on the incoming optical path is not required, it is preferred that a diffraction efficiency of the holographic element 152 be heightened to set a transmission efficiency of the holographic element 152 to almost zero. In this case, a combination of the holographic element 152 and the 1/4-λ plate 69 function functions as an isolator to prevent the light L4R or L5R from returning to the light source 52. Therefore, in cases where a semiconductor laser is utilized as the light source 52, any light does not return to an active layer of the semiconductor laser. Accordingly, noises induced by the light returning to the semiconductor laser can be prevented.

Also, because the light source 52 and the photo detector 153 are located on the same substrate 154, the light source 52 and the photo detector 153 can be closely arranged each other. Therefore, a relative position between the light source 52 and the photo detector 153 can be easily set at a high accuracy. For example, the relative position can

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be set at an accuracy within several μm. Accordingly, a manufacturing cost of the optical head apparatus 151 can be lowered, and the optical head apparatus 151 can be moreover manufactured at a small size, in a light weight, and at a low cost.

Also, the light source 52 is electrically connected with an external circuit through first wirings, and the photo detector 153 is electrically connected with another external circuit through second wirings. In this case, because the light source 52 and the photo detector 153 are located on the same substrate 154, the first and second wirings can pass on an X3-Y3 plane in common. Therefore, the light source 52 and the photo detector 153 can be easily and automatically connected with the external circuits. In addition, because reference lines required to connect the light source 52 and the photo detector 153 with the external circuits are only drawn on the X3-Y3 plane, the relative position between the light source 52 and the photo detector 153 can be easily set at a high accuracy

In the sixteenth reference apparatus, the optical head apparatus 151 with the holographic element 152 is described. However, in cases where the intensity of the incident light L3 is sufficient, it is applicable that a hologram having a small grating pitch or a blazed hologram be utilized in place of the holographic element 152. In this case, pieces of information can be reliably recorded or reproduced on or from an information medium regardless of whether the information medium is thick or thin. Also, because no beam splitter is utilized in the optical head apparatus 151, the optical head apparatus 151 can be manufactured at a small size, in a light weight, and at a low cost. Also, because optical parts of the optical head apparatus 151 are located along its optical axis, the optical head apparatus 151 stably operated can be obtained even though a circumstance temperature largely varies and the apparatus is operated for a long time.

(Seventeenth Reference Apparatus)

An optical head apparatus manufactured in a small size and stably operated is described with reference to Fig. 52 according to a seventeenth reference apparatus.

Fig. 52 is a constitutional view of an optical head apparatus according to a seventeenth reference apparatus.

As shown in Fig. 52, an optical head apparatus 161 for recording or reproducing pieces of information on or from the information medium 23 or 25, comprises the light source 52 for radiating the incident light L3 linearly polarized in a first direction, the collimator lens 53, a polarizing separation film 162 formed on a front surface of a transparent substrate 162 for reflecting the incident light L3 linearly polarized in the first direction and transmitting light linearly polarized in a second direction perpendicular to the first direction, the 1/4-λ plate 69, the hologram lens 26 (or 26M, 32, 33, 42, 135 or 142), the objective lens 27, the actuating unit 58, a reflection-type hologram 164 formed on a rear surface of the transparent substrate 162 for diffracting and reflecting the light L4R, L5R, and the photo detector 57.

In the above configuration, the incident light L3 linearly polarized in a first direction is radiated from the light source 52 and is collimated by the collimator lens 53. Thereafter, all of the incident light L3 is reflected by the polarizing separation film 162 because the incident light L3 is linearly polarized in the first direction. Therefore, the incident light L3 is directed in an upper direction. Thereafter, the linear polarization of the incident light L3 is changed to a circular polarization in the 1/4-λ plate 69, and a part of the incident light L3 transmits through the hologram lens 26 to form the transmitted light L4. Also, a remaining part of the incident light L3 is diffracted by the hologram lens 26 to form the diffracted light L5. Thereafter, the light L4, L5 are converged by the objective lens 27, and the converging spot S1 of the transmitted light L4 (or the converging spot S2 of the diffracted light L5) is formed on the first information medium 23 (or the second information medium 25). Thereafter, the transmitted light L4R (or the diffracted light L5R) circularly polarized in reverse again passes through the converging lens 27 in the same manner as in the sixteenth embodiment, and a part of the transmitted light L4R transmits through the hologram lens 26 without any diffraction or a part of the diffracted light L5R is again diffracted by the hologram lens 26. Thereafter, the transmitted light L4R (or the diffracted light L5R) circularly polarized in reverse is changed to the light L4R (or L5R) linearly polarized in a second direction perpendicular to the first direction by the 1/4-λ plate 69. Thereafter, all of the light L4R (or L5R) is refracted by the polarizing separation film 162 and is diffracted and reflected by the hologram 164. Thereafter, the light L4R (or L5R) transmits through the polarizing separation film 162 and is converged by the collimator lens 53 to form a plurality of converging spots on the photo detector 57. Therefore, an information signal expressing a piece of information recorded on the information medium 23 (or 25) and servo signals such as a focus error signal and a tracking error signal are obtained in the photo detector 57 in the same manner as in the sixth reference apparatus.

Accordingly, because the compound objective lens having two focal points is utilized in the optical head apparatus 161, pieces of information can be reliably recorded or reproduced on or from an information medium regardless of whether the information medium is thick or thin.

Also, because the incident light L3 incident on the polarizing separation film 162 is collimated, a reflectivity for the incident light L3 is uniform over the entire film 162. Therefore, a diffraction-limited spot of the light L4 or L5 can be easily formed on the information medium 23 or 25. Also, because the light L4R, L5R incident on the polarizing separation film 162 are collimated, a transmissivity for the light L4R, L5R is uniform over the entire film 162. Therefore, an offset occurring in the servo signals can be prevented.

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Also, because all of the incident light L3 transmits through the hologram 164 on the outgoing optical path and because all of the light L4R or L5R is diffracted by the hologram 164 on the incoming optical path, a utilization efficiency of the incident light L3 can be enhanced. Therefore, even though a radiation intensity of the incident light L3 in the light source 52 is low, the information signal and the servo signals having a high signal-noise ratio can be reliably obtained.

Also, because a hybrid element composed of the film 162, the substrate 163 and the hologram 164 functions as a beam splitter and a rising mirror, the optical head apparatus 161 can be manufactured at a small size, in a light weight, and at a low cost.

Also, because optical parts of the optical head apparatus 161 are located along its optical axis, the optical head apparatus 161 stably operated can be obtained even though a circumstance temperature largely varies and the apparatus is operated for a long time.

Also, a combination of the film 162 and the 1/4-λ plate 69 function functions as an isolator to prevent the light L4R or L5R from returning to the light source 52. Therefore, in cases where a semiconductor laser is utilized as the light source 52, any light does not return to an active layer of the semiconductor laser. Accordingly, noises induced by the light returning to the semiconductor laser can be prevented.

Also, it is preferred that the hologram 164 be blazed. In this case, because the generation of unnecessary diffracted light such as minus first-order diffracted light in the hologram 164 is prevented, a diffraction efficiency of the hologram 164 for changing light to first-order diffracted light can be set to almost 100%. Therefore, the incident light L3 can be efficiently utilized to obtain the signals.

Also, because light incident on the hologram 164 is diffracted to first-order diffracted light, a chromatic aberration occurring in the light L4R, L5R can be compensated in the hologram 164. Therefore, the servo signals can be stably obtained.

In the seventeenth reference apparatus, the collimator lens 53 is located between the light source 52 and the film 162. However, the collimator lens 53 is not necessary in the optical head apparatus 161.

Also, the optical head apparatus 161 with the film 162 and the 1/4-λ plate 69 is described. However, in cases where the intensity of the incident light L3 is sufficient, it is applicable that a reflection film having a reflectivity of almost 1/3 be utilized in place of the film 162 and the 1/4-λ plate 69 be omitted. In this case, pieces of information can be reliably recorded or reproduced on or from an information medium regardless of whether the information medium is thick or thin. Also, because a hybrid element composed of the film 162, the substrate 163 and the hologram 164 functions as a beam splitter and a rising mirror, the optical head apparatus 161 can be manufactured at a small size, in a light weight, and at a low cost. Also, because optical parts of the optical head apparatus 161 are located along its optical axis, the optical head apparatus 161 stably operated can be obtained even though a circumstance temperature largely varies and the apparatus is operated for a long time.

In the sixth to seventeenth reference apparatus, pieces of information can be reliably recorded or reproduced on or from an information medium regardless of whether the information medium represents a conventional optical disk such as a compact disk having a thickness T2 of about 1.2mm or a prospective high density optical disk having a thickness T1 ranging from 0.4mm to 0.8mm. However, when the information recorded or reproduced on or from the information medium, it is required to examine the thickness of the information medium in advance. Therefore, in cases where a piece of distinguishing information is recorded on the information medium in advance to distinguish the thickness of the information medium, it is convenient for a user. Because no distinguishing information is recorded on the conventional optical disk, it is preferred that the distinguishing information be recorded on the prospective high density optical disk appearing on the market in the future. Therefore, a high density optical disk with the distinguishing information is described according to first and second embodiments.

(First Embodiment)

Fig. 53 is a diagonal view of a high density optical disk according to a first embodiment, a cross sectional view of the disk being partially shown.

As shown in Fig. 53, a high density optical disk 171 is partitioned into an outer region 171a and an inner region 171b. The outer region 171a occupies a large part of the optical disk 171, and an information recording substrate 171c of the outer region 171a has the thickness T1, and the information recording substrate 171c of the inner region 171b has the thickness T2. A plurality of first recording pits 172 are formed on the information recording substrate 171c of the outer region 171a at narrow intervals in series to record pieces of information at a high density. Also, a plurality of second recording pits 173 are formed on the information recording substrate 171c of the inner region 171b at ordinary intervals in series to record pieces of distinguishing information at an ordinary density of a compact disk. The distiguishing information inform that the optical disk 171 has the thickness T1. The thickness T1 of the outer region 171a, for example, ranges from 0.4mm to 0.8mm, and the thickness T2 of the inner region is, for example, about 1.2mm.

In the above configuration, the diffracted light L5 according to the first or second reference apparatus, (or the transmitted light L4 according to the third reference apparatus) is initially converged on an inner region of the information

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medium 23, 25 while performing a focus control corresponding to the second information medium 25 having the thickness T2. In cases where the information medium 23 or 25 is the optical disk 171, a piece of distinguishing information informing that the optical disk 171 having the thickness T1 is converged by the light L5 (or L4) is detected. Thereafter, the transmitted light L4 (or the diffracted light L6) is automatically converged on the outer region 171a of the optical disk 171 while performing a focus control corresponding to the first information medium 23 having the thickness T1.

In contrast, in cases where the information medium 23 or 25 is a thick type of conventional optical disk having a thickness T2, no distinguishing information is detected when the light L5 (or L4) is converged on the inner region 171b of the conventional optical disk. In this case, the focus control corresponding to the second information medium 25 is continued to detect an information signal expressing a piece of information recorded on the conventional optical disk.

Accordingly, in cases where one of the optical head apparatuses shown in Figs. 21, 27, 30, 31, 32, 33, 37, 38, 40A, 43, 44, 50 and 52 is utilized, pieces of information can be automatically recorded or reproduced on or from an information medium regardless of whether the information medium is thin or thick.

Also, because only the distinguishing information is recorded in the inner region, the inner region can be small. Therefore, a memory capacity of the optical disk 171 is not lowered by the addition of the second recording pit 173.

(Second Embodiment)

Fig. 54 is a diagonal view of a high density optical disk according to a second embodiment, a cross sectional view of the disk being partially shown.

As shown in Fig. 54, a high density optical disk 174 is partitioned into an outer region 174a and an inner region 174b. The outer region 174a occupies a large part of the optical disk 174. The optical disk 174 has a uniform thickness of T1. The first recording pits 172 are formed on an information recording substrate 174c of the outer region 174a to record pieces of information at a high density. Also, a plurality of second recording pits 175 having a large size are formed on the information recording substrate 174c of the inner region 174b at wide Intervals to record pieces of distinguishing information at a lower density than the ordinary density. The distinguishing information inform that the entire optical disk 174 has the thickness T1. The thickness T1 of the optical disk 174, for example, ranges from 0.4mm to 0.8mm.

In the above configuration, the diffracted light L5 according to the first or second reference apparatus (or the transmitted light L4 according to the third reference apparatus) is initially converged on an inner region of the information medium 23 or 25 while performing a focus control corresponding to the second information medium 25 having the thickness T2. In cases where the information medium 23 or 25 is the optical disk 174, the light L5 (or L4) is converged on each of the second recording pits 175 in defocus. However, because each of the second recording pits 175 is large in size, a converging spot of the light L5 (or L4) is reliably formed in one of the second recording pits 175. Therefore, a piece of distinguishing information, which informs that the optical disk 174 having the thickness T1 is converged by the light L5 (or L4), is detected. Thereafter, the transmitted light L4 (or the diffracted light L6) is automatically converged on the outer region 174a of the optical disk 174 while performing a focus control corresponding to the first information medium 23 having the thickness T1.

In contrast, in cases where the information medium 23 or 25 is a thick type of conventional optical disk having a thickness T2, no distinguishing information is detected when the light L5 (or L4) is converged on the inner region 174b of the conventional optical disk. In this case, the focus control corresponding to the second information medium 25 is continued to detect an information signal expressing a piece of information recorded on the conventional optical disk.

Accordingly, in cases where one of the optical head apparatuses shown in Figs. 21, 27, 30, 31, 32, 33, 37, 38, 40A, 43, 44, 50 and 52 is utilized, pieces of information can be automatically recorded or reproduced on or from an information medium regardless of whether the information medium is thin or thick.

Also, because only the distinguishing information is recorded in the inner region of the optical disk 174, the inner region can be small. Therefore, a memory capacity of the optical disk 174 is not lowered by the addition of the second recording pit 173.

Also, because the thickness of the optical disk 174 is uniform, the optical disk 174 can be easily manufactured at a low cost. Also, the optical disk 174 can be thinned.

An optical disk apparatus with one of the optical head apparatuses in which it is automatically judged whether a high density optical disk having the thickness T1 or a conventional optical disk having the thickness T2 is utilized is described.

Fig. 55 is a block diagram of an optical disk apparatus with one of the optical head apparatuses shown in Figs. 21, 27, 30, 31, 32, 33, 37, 38, 40A, 43, 44, 50 and 52.

Fig. 56 is a flow chart showing the operation of the optical disk apparatus shown in Fig. 55.

As shown in Fig. 55, an optical disk apparatus 176 for recording or reproducing pieces of information on or from the high density optical disk 171 (or 174) or the conventional optical disk 25, comprises the optical head apparatus 51 (or 61, 65, 67, 70, 71, 81, 91, 101, 111, 121, 151 or 161), a moving means 177 such as a feed mechanism for moving

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the optical head apparatus 51 to a prescribed position, and a rotating means 178 such as a spindle motor for rotating the high density optical disk 171 (or 174) or the conventional optical disk 25.

In the above configuration, the high density optical disk 171 or the conventional optical disk 25 is set to a prescribed position of the optical disk apparatus 176, and the optical disk 171 or 25 is rotated by the rotating means 178. Thereafter, the optical head apparatus 51 is moved to a position just under an innermost recording track of the optical disk 171 or 25 in a step 211, and the diffracted light L5 is converged on the innermost recording track of the optical disk 171 or 25 while performing a focus control corresponding to the conventional optical disk 25 of the thickness T2 in a step 212. Thereafter, a tracking control is performed, and a piece of information recorded on the innermost recording track of the optical disk 171 or 25 is detected in a step 213. Thereafter, it is judged in a step 214 whether the information agrees with a piece of distinguishing information informing that the optical disk 171 having the thickness T1 is set to the optical disk apparatus 176.

In cases where the high density optical disk 171 is set to the optical disk apparatus 176, the distinguishing information is detected. Thereafter, the transmitted light L4 is automatically converged on the optical disk 171 while performing a focus control corresponding to the optical disk 171 of the thickness T1 in a step 215. Therefore, pieces of information are recorded or reproduced on or from the optical

Claims

1. An optical disk, comprising:

an information recording substrate (171) having a first region (171a) having a first thickness (T1), and a plurality of first recording pits (172) placed at the first region of the information recording substrate for recording pieces of recording information at a first recording density;

characterised in that the information recording substrate also has a second region (171b) having a second thickness (T2) larger than the first thickness (T1);

and by a plurality of second recording pits (173) placed at the second region of the information recording substrate for recording distinguishing information at a second recording density which is lower than the first recording density, the distinguishing information indicating that the first region of the information recording substrate has the first thickness (T1).

2. An optical disk, comprising:

an information recording substrate (174) having a first thickness thinner than that of a compact disk;

a plurality of first recording pits (172) placed at a first region (174a) of the information recording substrate for recording pieces of recording information at a first recording density;

characterised in that the information recording substrate additionally has a second region (174b) and by a plurality of second recording pits (175) placed at a second region of the information recording substrate for recording distinguishing information at a second recording density lower than the first recording density, the distinguishing information indicating that the first region of the information recording substrate has the first thickness.

BNSDOCID: <EP_____0836178A1_I_>

FIG. 1
PRIOR ART

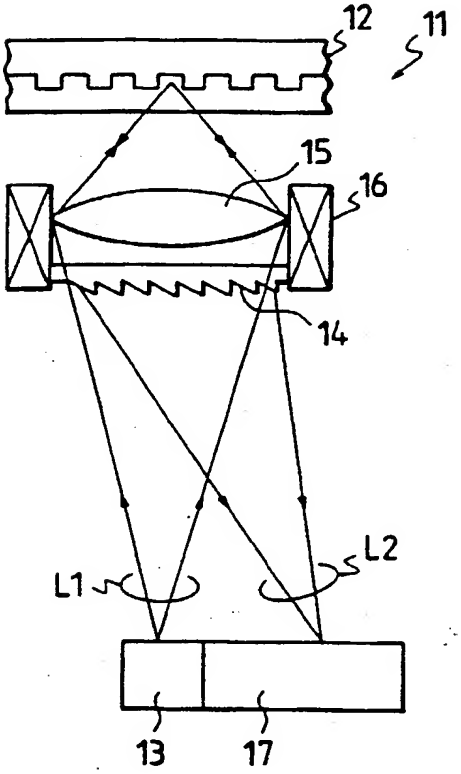


FIG. 2A
PRIOR ART

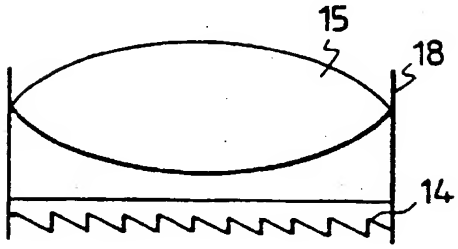
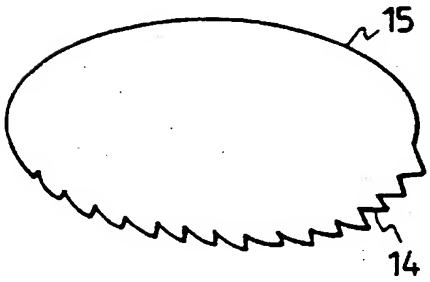
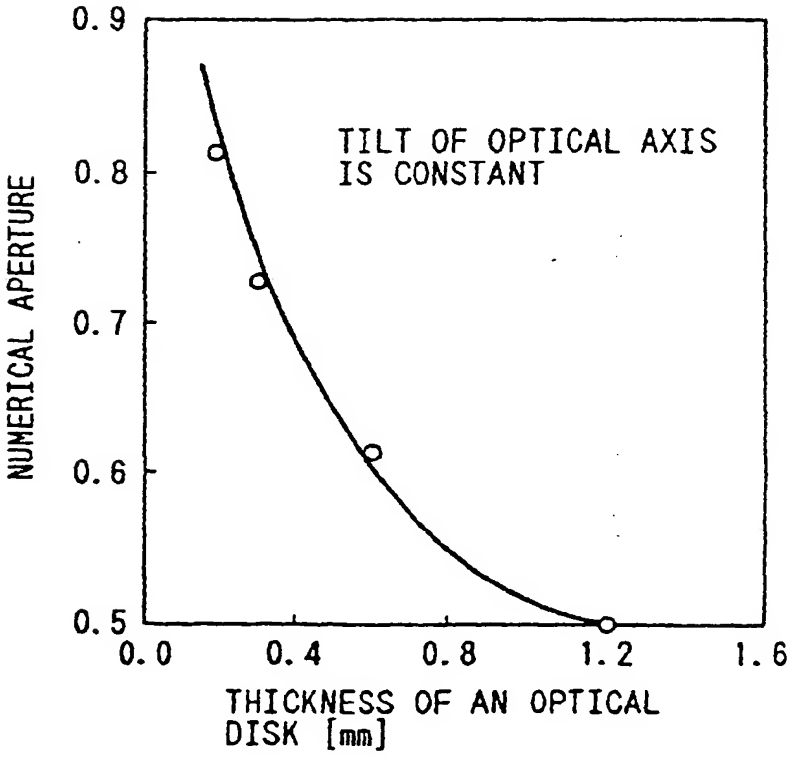


FIG. 2B
PRIOR ART



BNSDOCID: <EP_____0836178A1_I_>

FIG. 3 PRIOR ART



BNSDOCID: <EP_____0836178A1_I_>

FIG. 4A

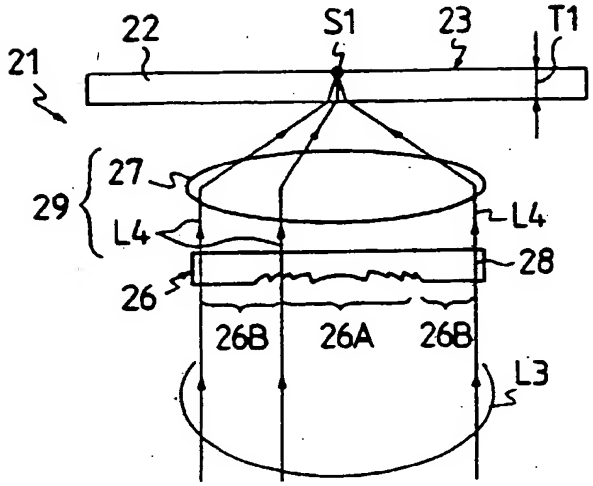


FIG. 4B

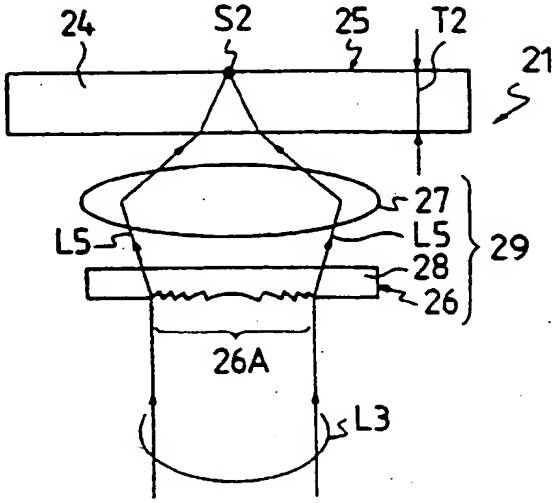
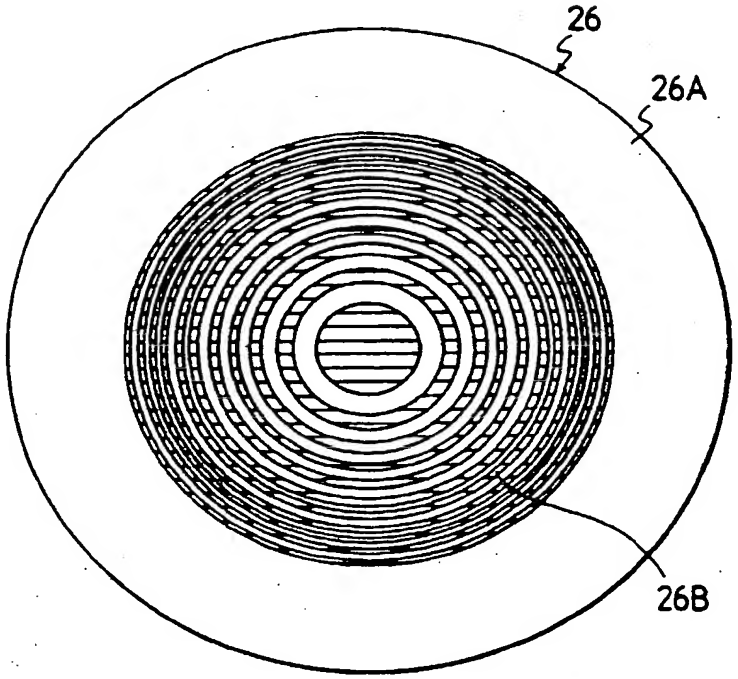


FIG. 5



BNSDOCID: <EP_____0836178A1_I_>

FIG. 6

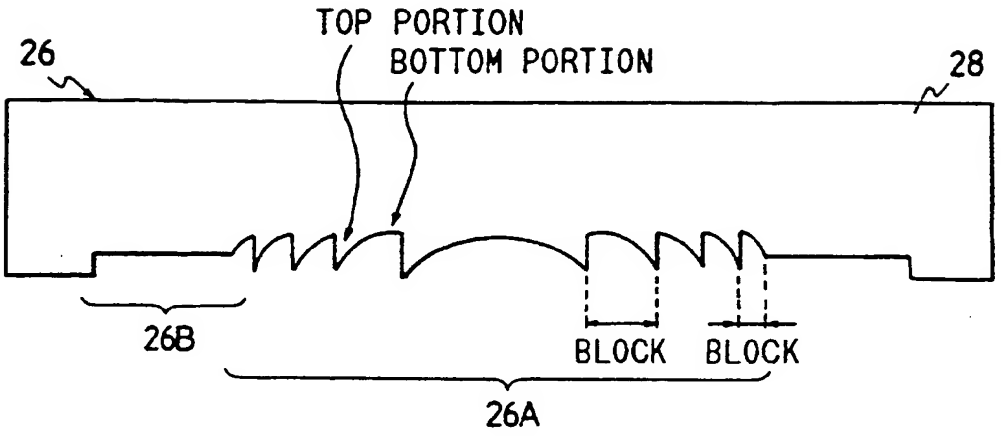
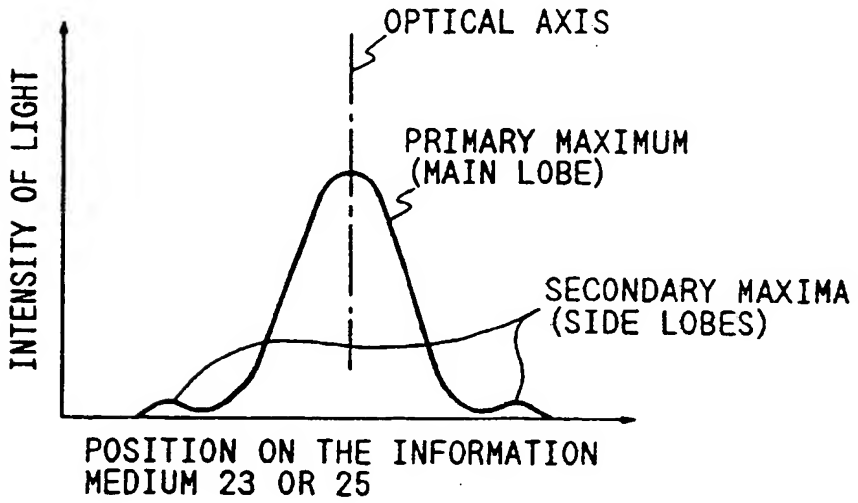


FIG. 7



BNSDOCID: <EP_____0836178A1_I_>

FIG. 8A

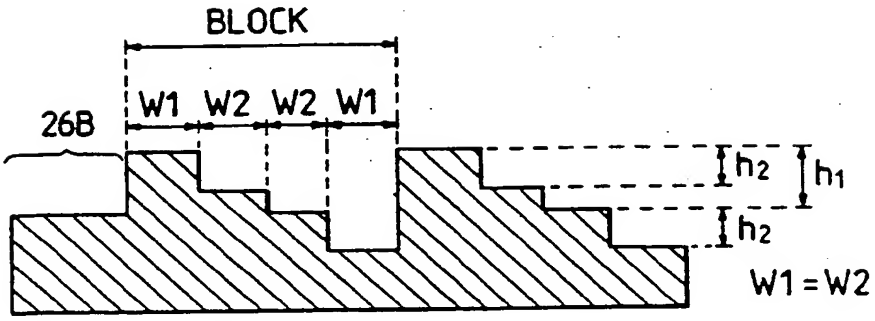
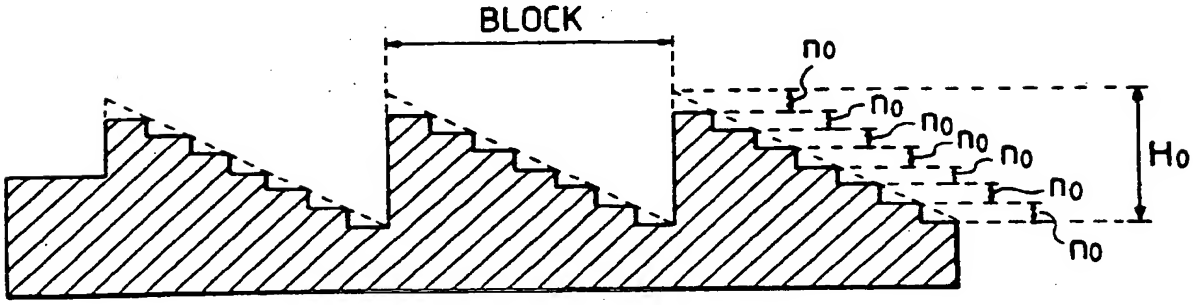


FIG. 8B



BNSDOCID: <EP_____0836178A1_I_>

FIG. 9A

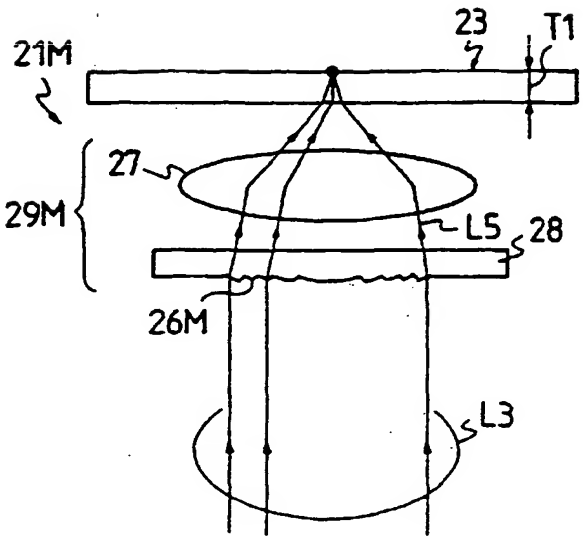


FIG. 9B

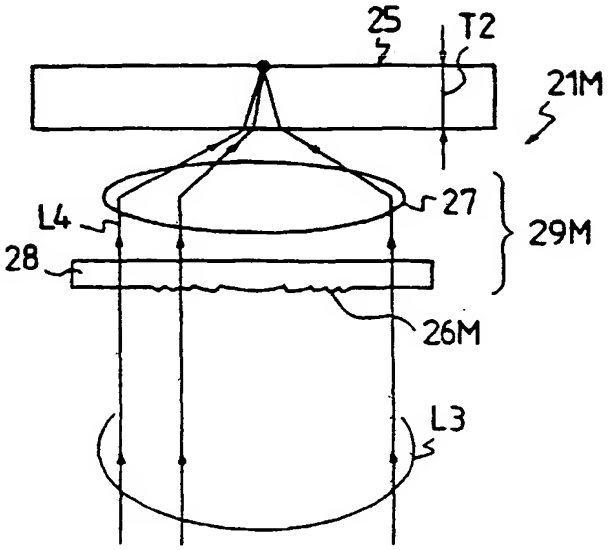


FIG. 10A

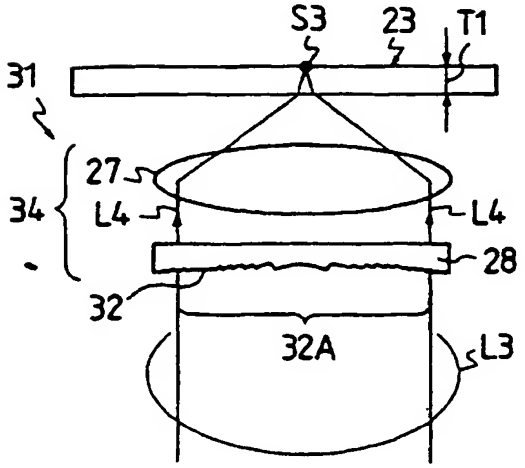
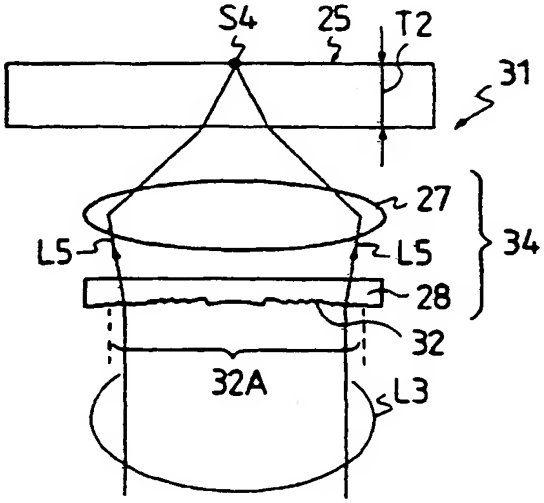


FIG. 10B



BNSDOCID: <EP_____0836178A1_I_>

FIG. 11

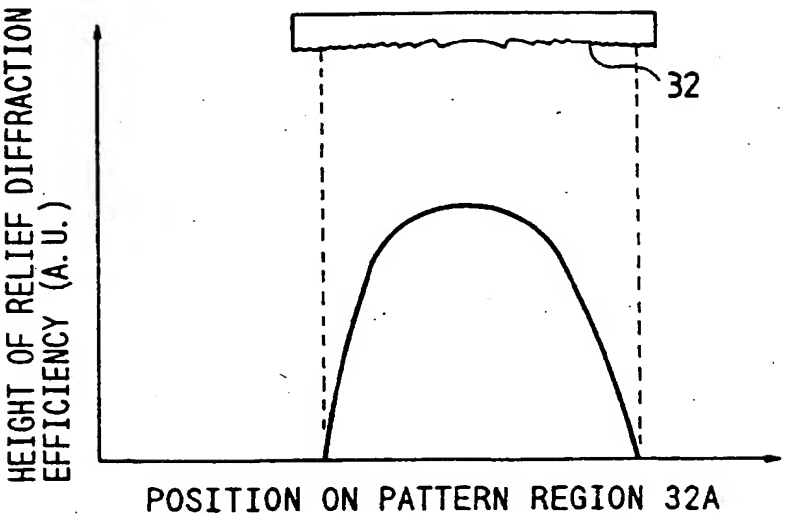


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FIG. 12A

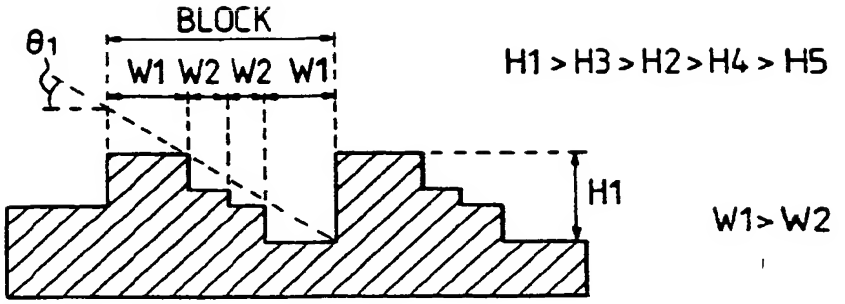


FIG. 12B

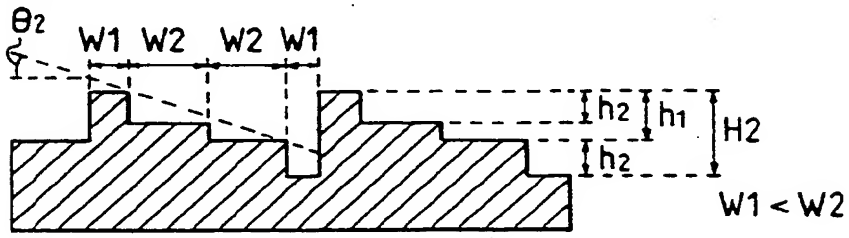


FIG. 12C

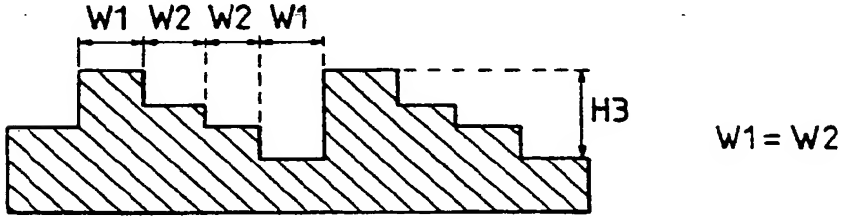


FIG. 12D

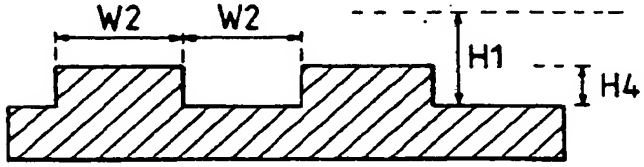
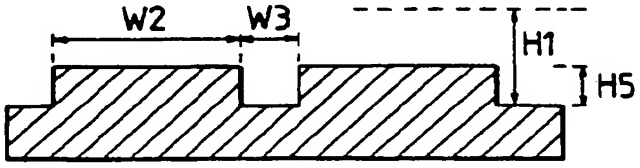


FIG. 12E



BNSDOCID: <EP_____0836178A1_I_>

FIG. 13A

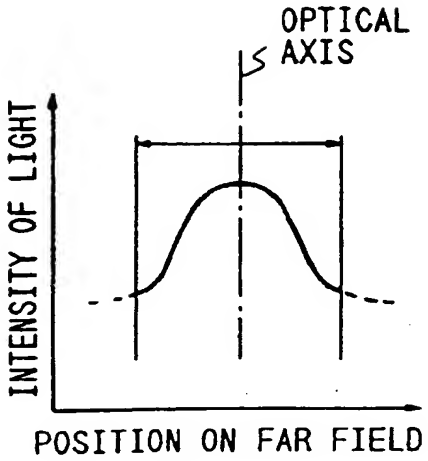


FIG. 13B

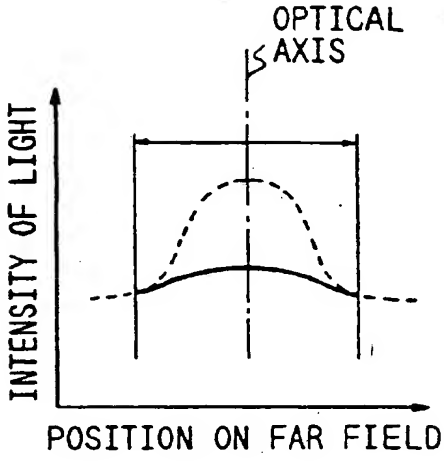


FIG. 14A

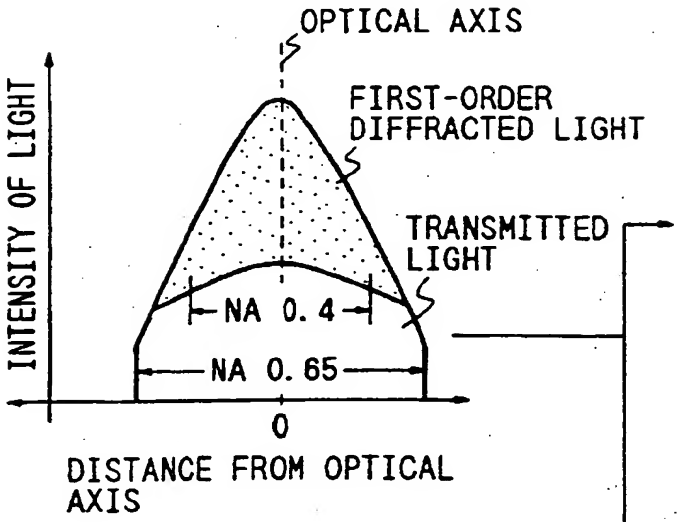


FIG. 14B

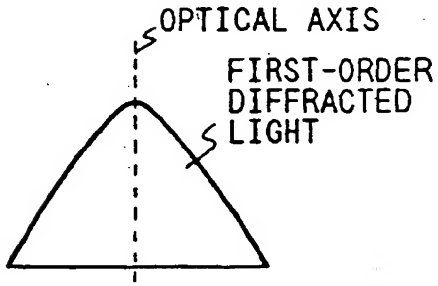
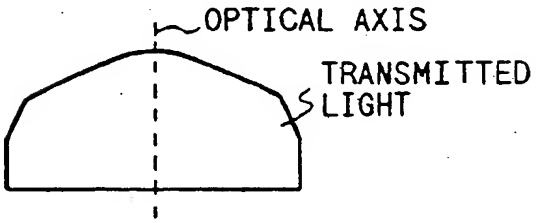


FIG. 14C



BNSDOCID: <EP_____0836178A1_I_>

FIG. 15A

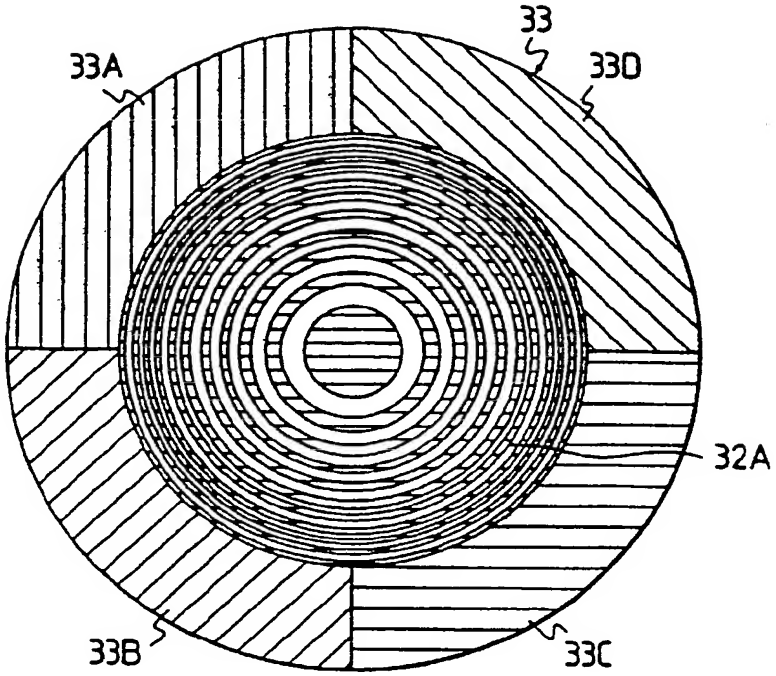


FIG. 15B

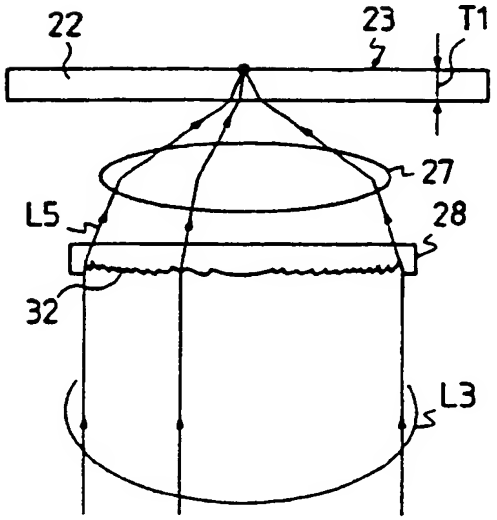
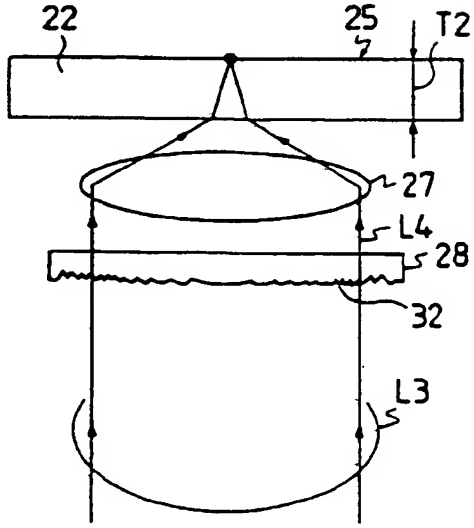


FIG. 15C



BNSDOCID: <EP_____0836178A1_I_>

FIG. 16A

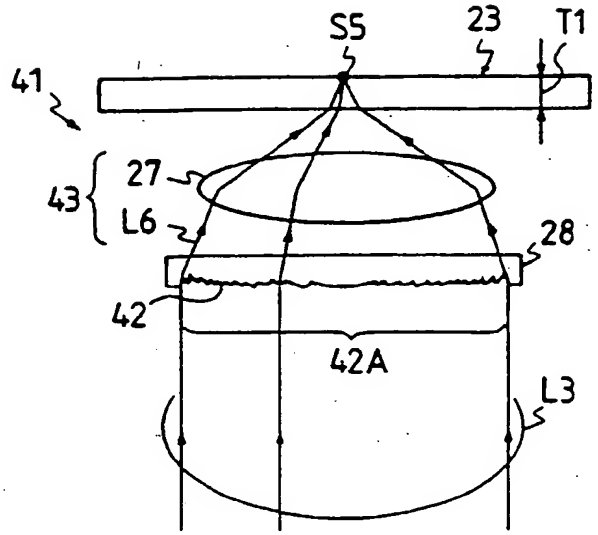


FIG. 16B

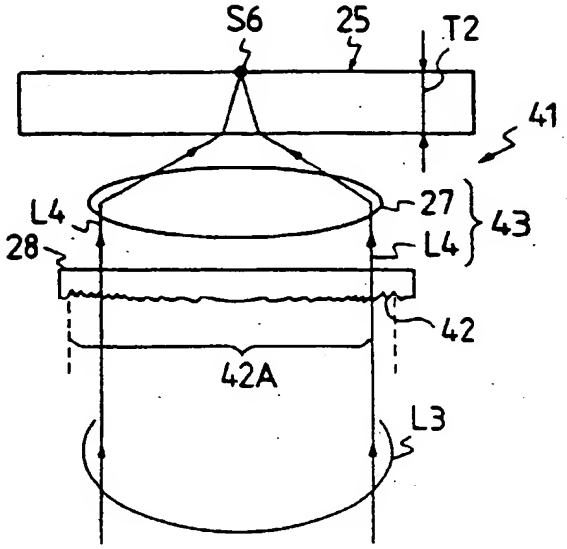
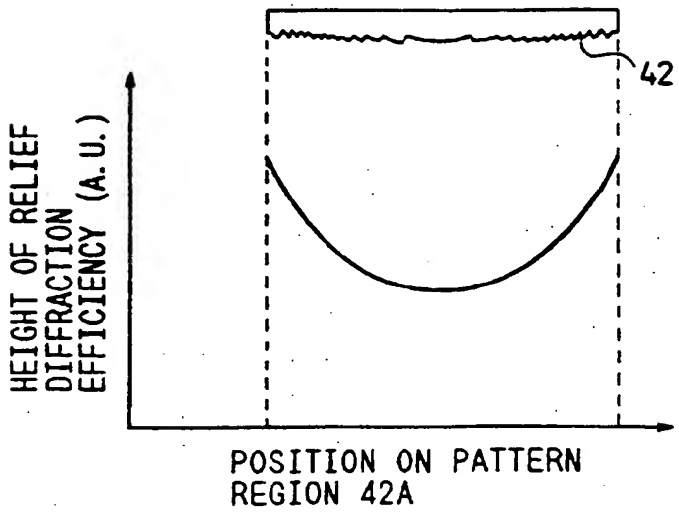


FIG. 17



BNSDOCID: <EP_____0836178A1_I_>

FIG. 18A

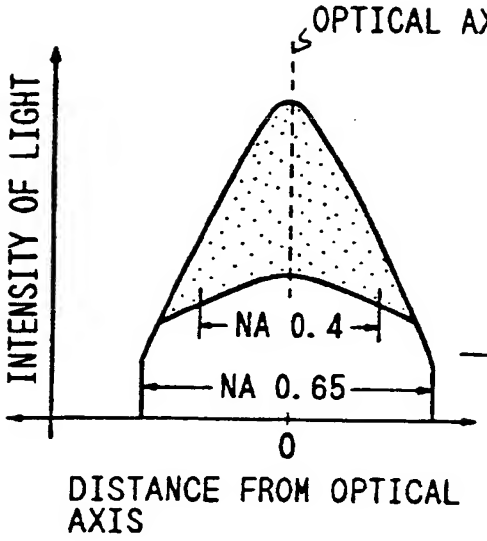


FIG. 18B

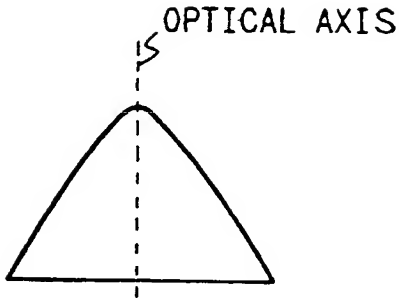


FIG. 18C

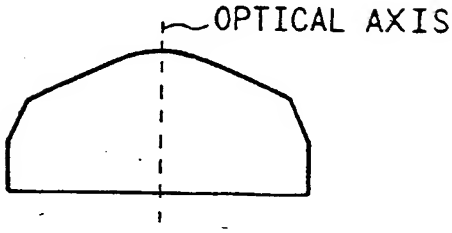


FIG. 19A

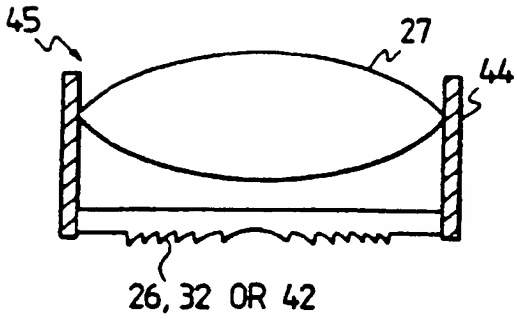


FIG. 19B

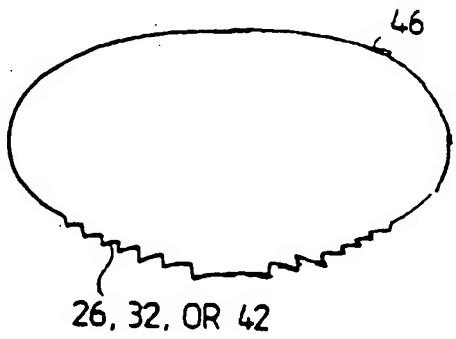
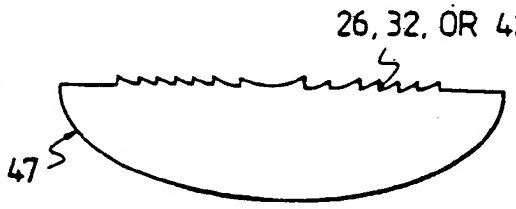
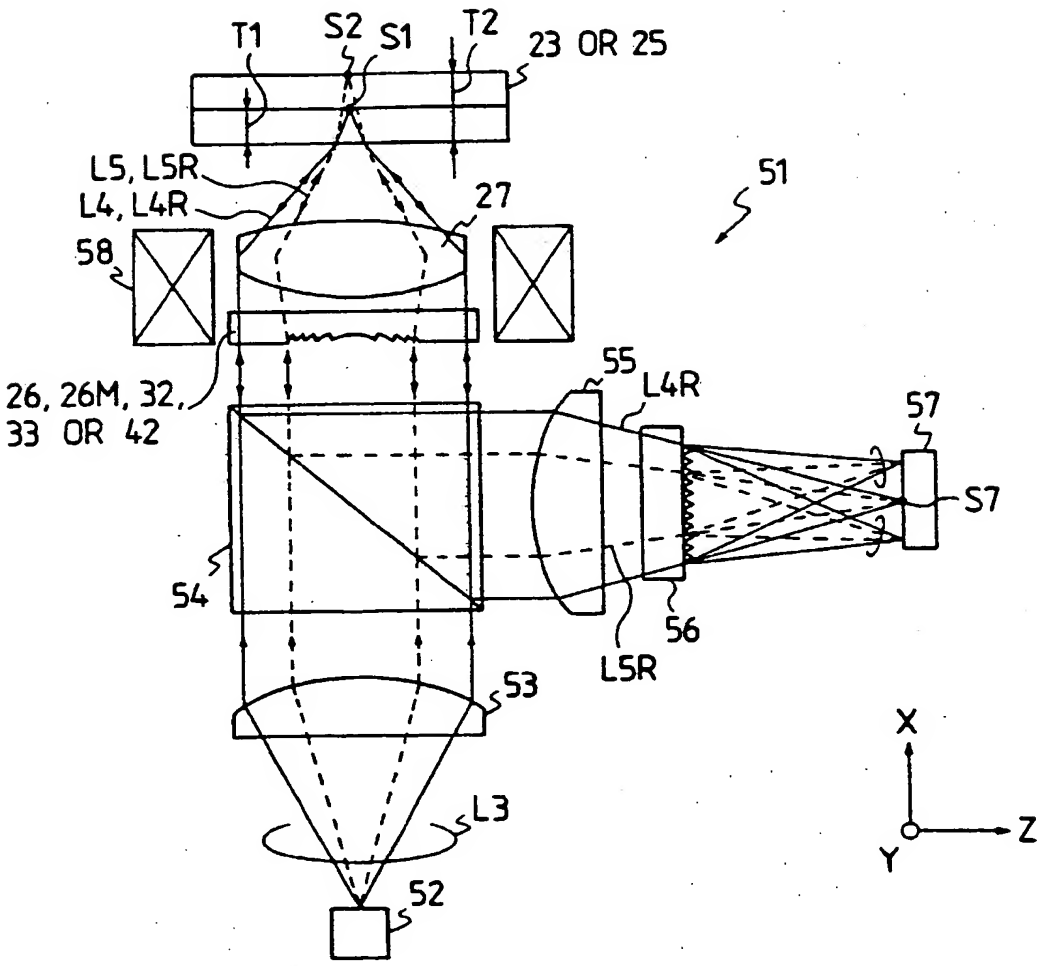


FIG. 20



BNSDOCID: <EP_____0836178A1_I_>

FIG. 21



BNSDOCID: <EP_____0836178A1_I_>

FIG. 22

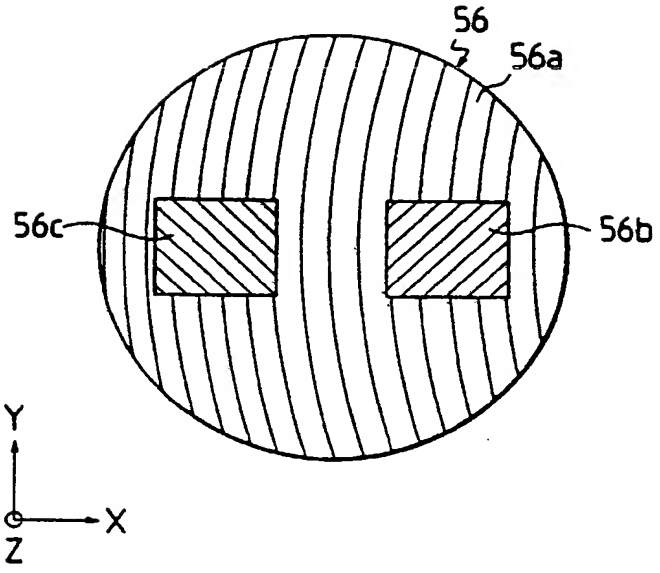
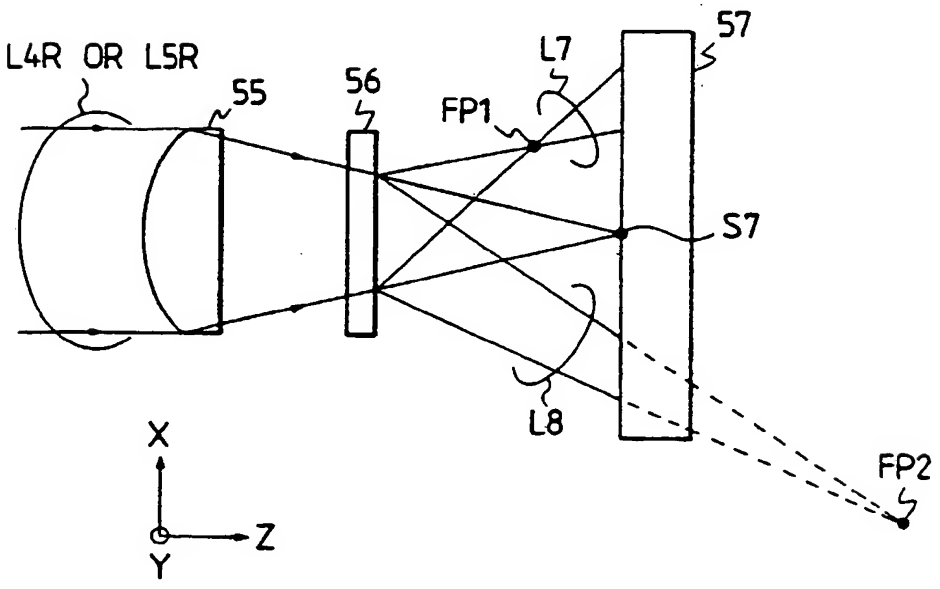


FIG. 23



BNSDOCID: <EP_____0836178A1_I_>

FIG. 24

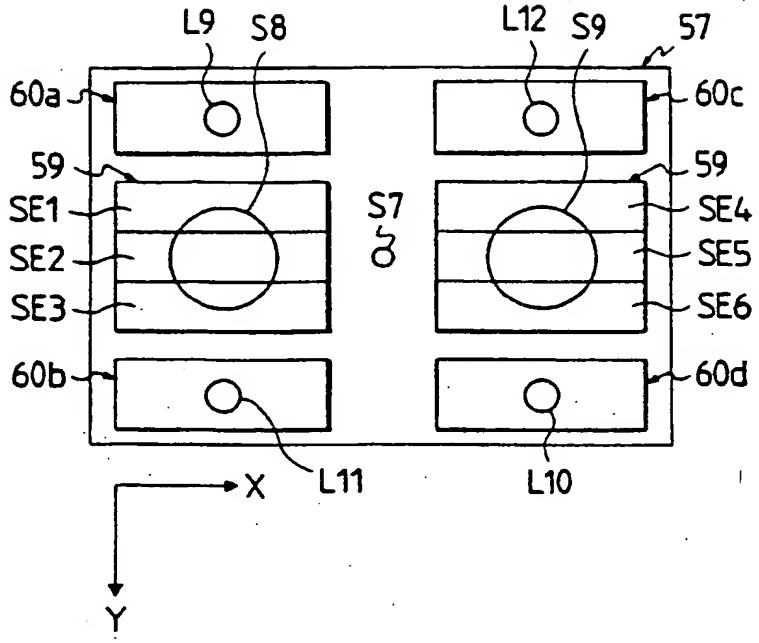


FIG. 25A

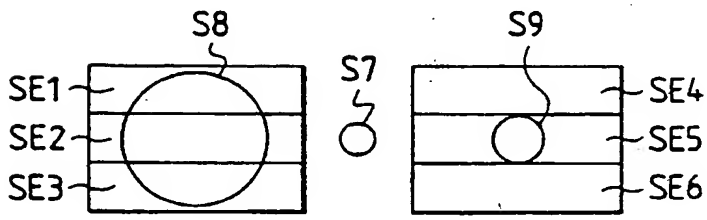


FIG. 25B

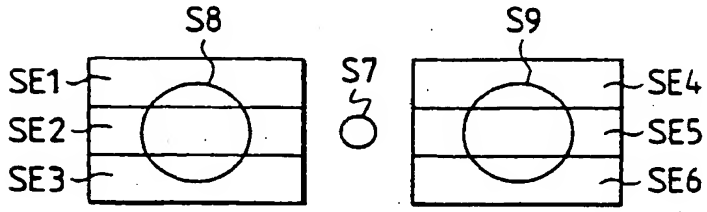
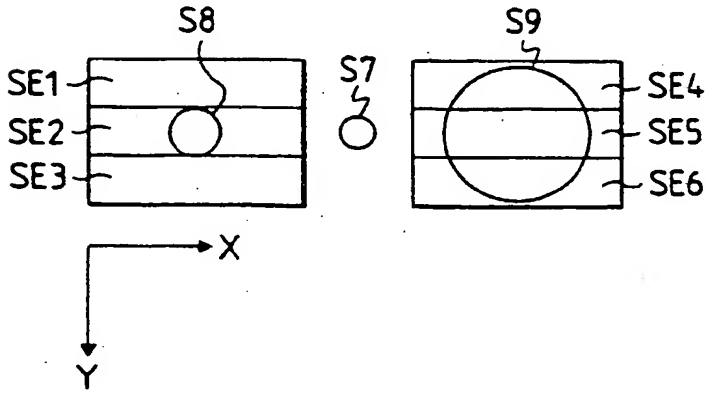


FIG. 25C



BNSDOCID: <EP_____0836178A1_I_>

FIG. 26

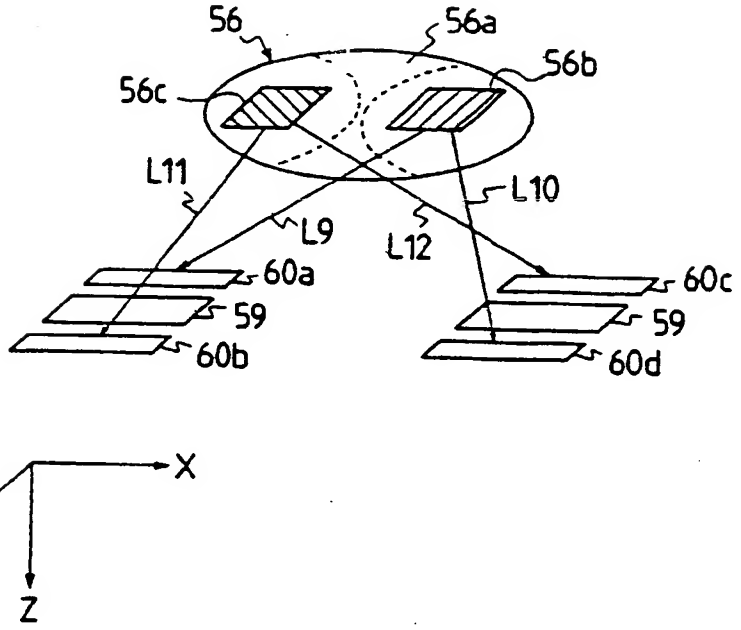
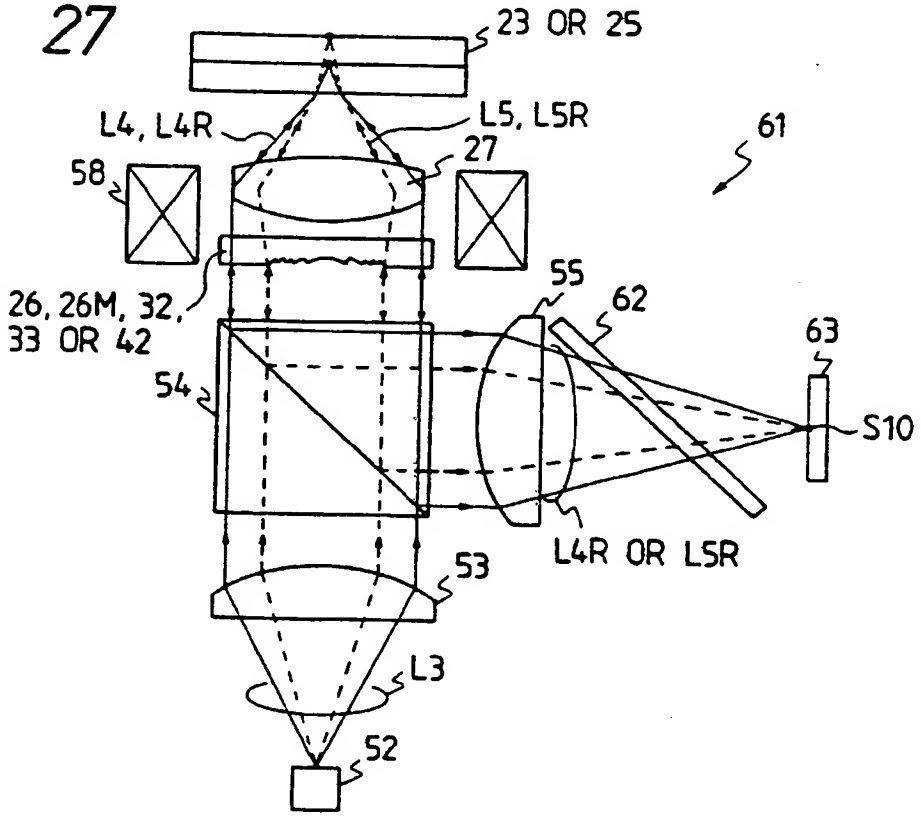


FIG. 27



BNSDOCID: <EP_____0836178A1_I_>

FIG. 28

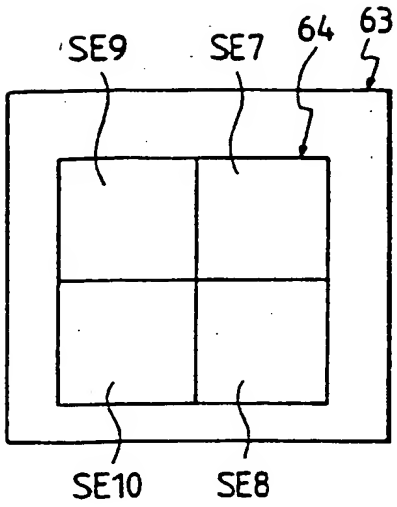


FIG. 29A

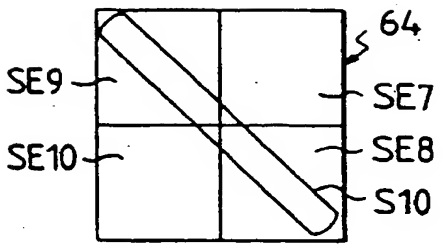


FIG. 29B

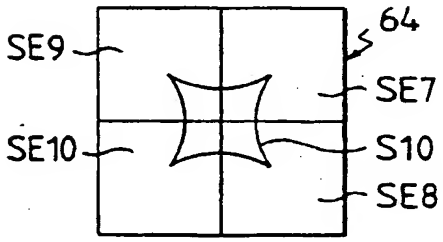


FIG. 29C

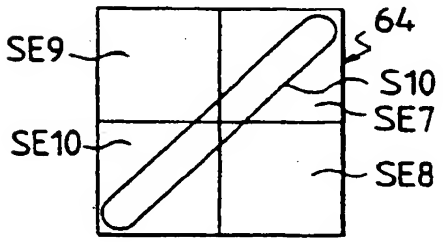
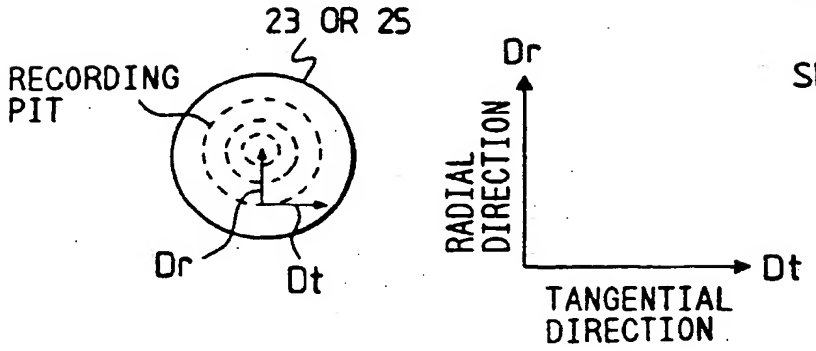
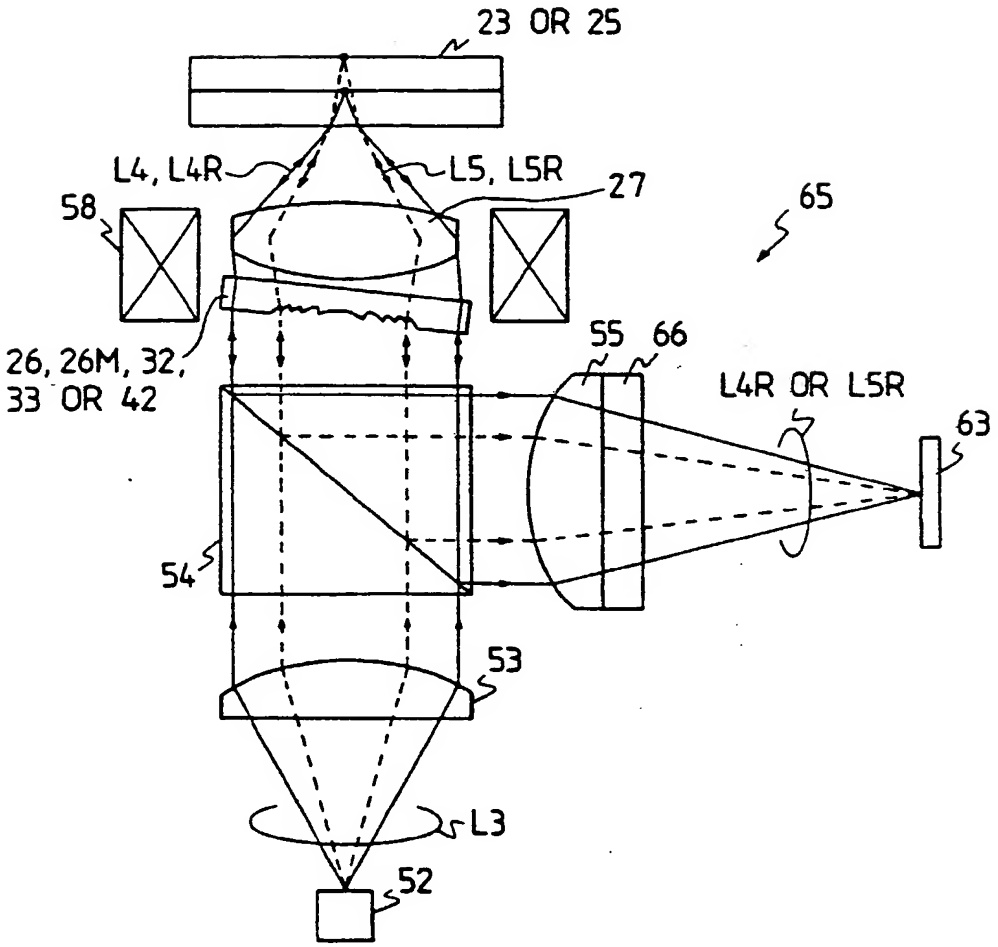


FIG. 29D



BNSDOCID: <EP_____0836178A1_I_>

FIG. 30



BNSDOCID: <EP_____0836178A1_I_>

FIG. 31

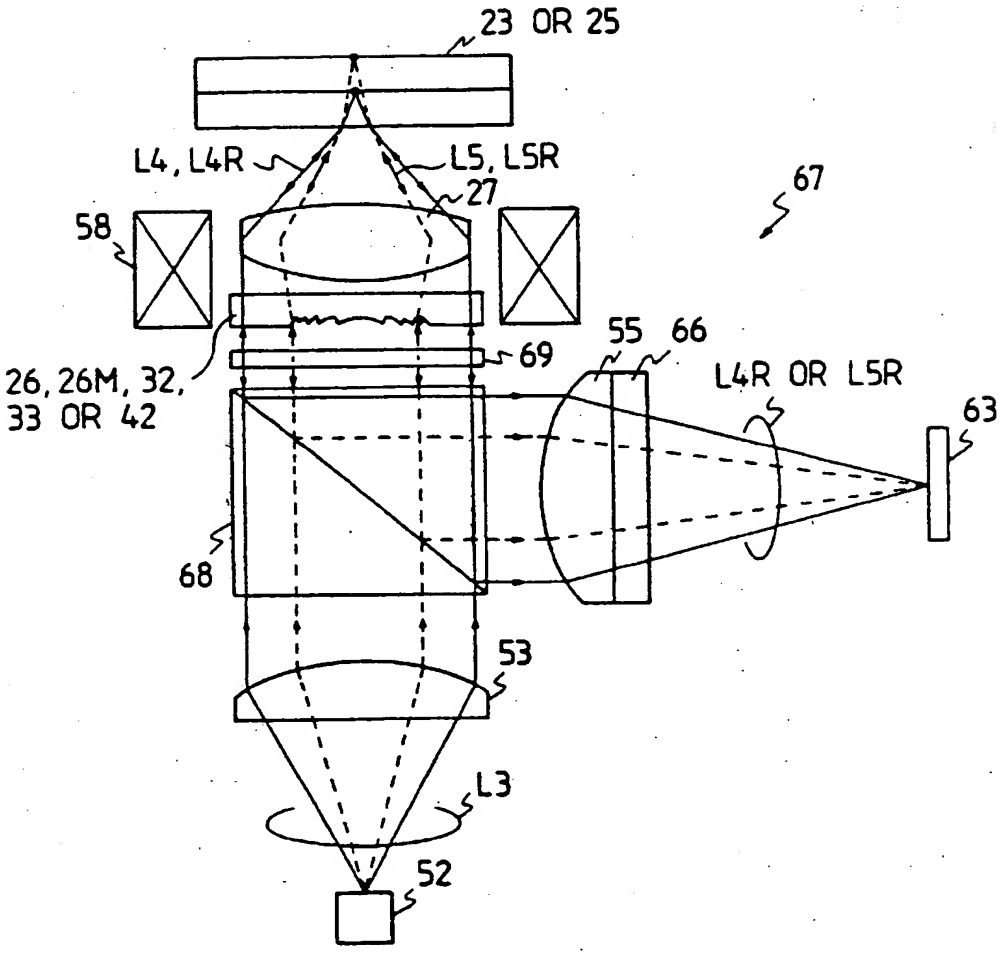


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FIG. 32

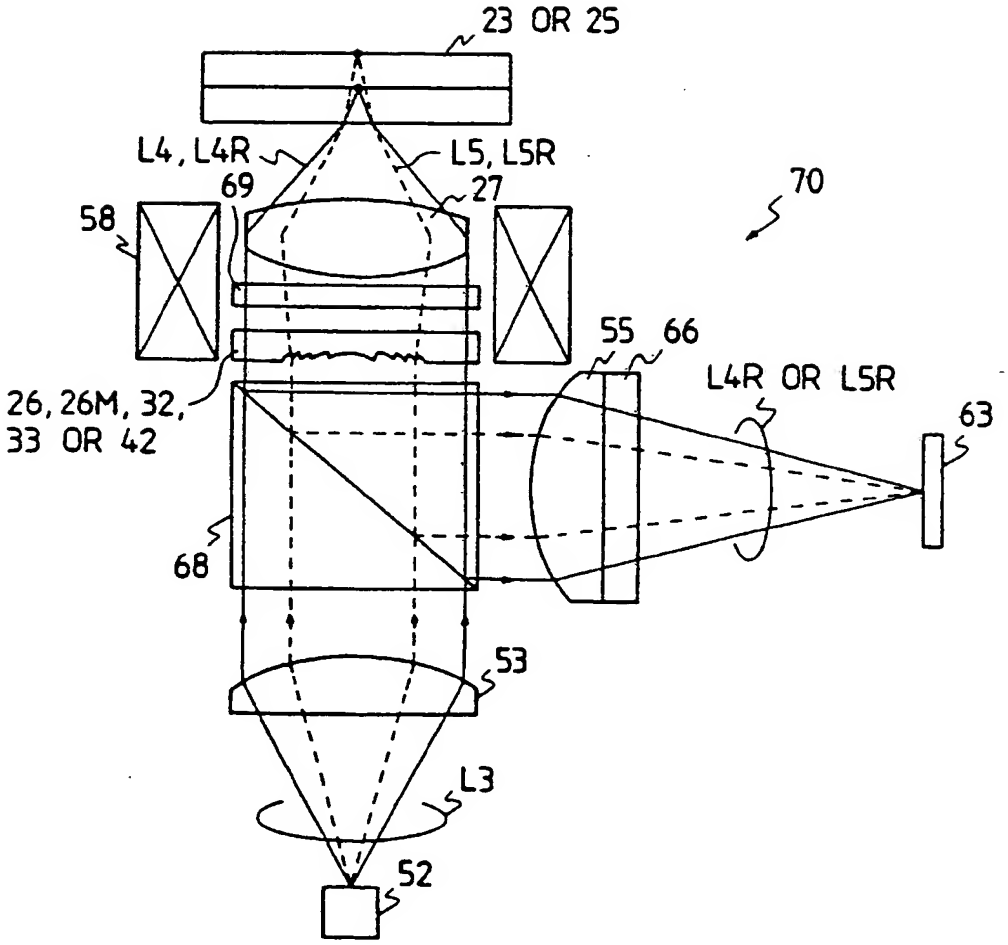

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FIG. 33

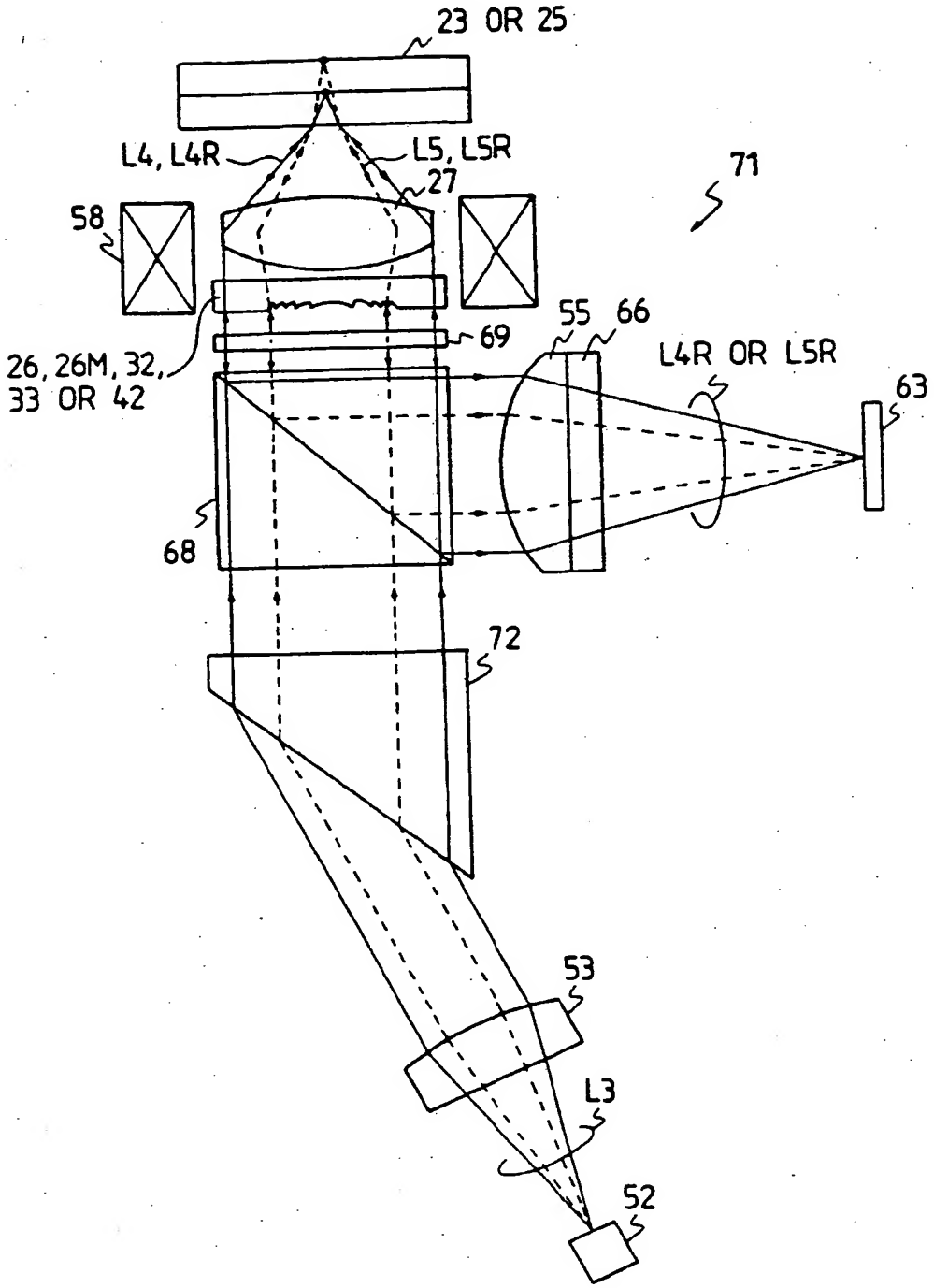

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FIG. 34

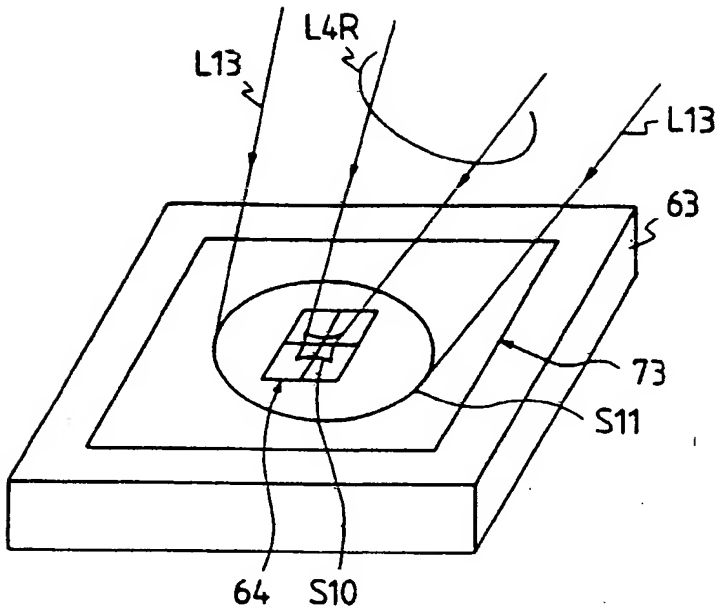

FIG. 37

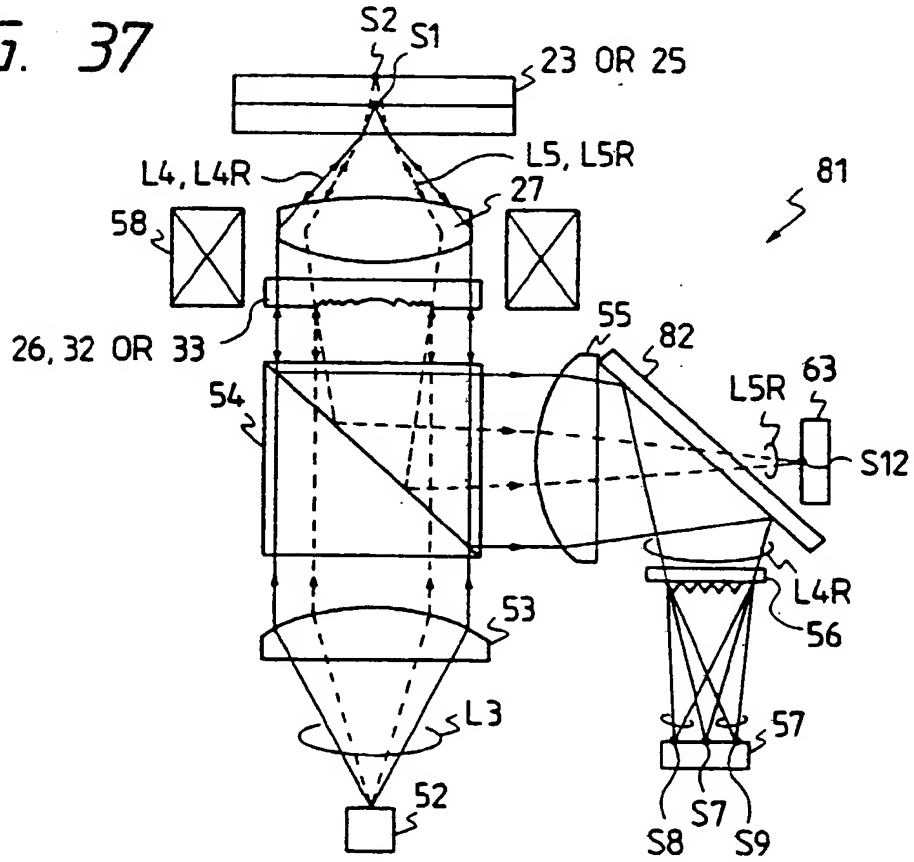

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FIG. 35A

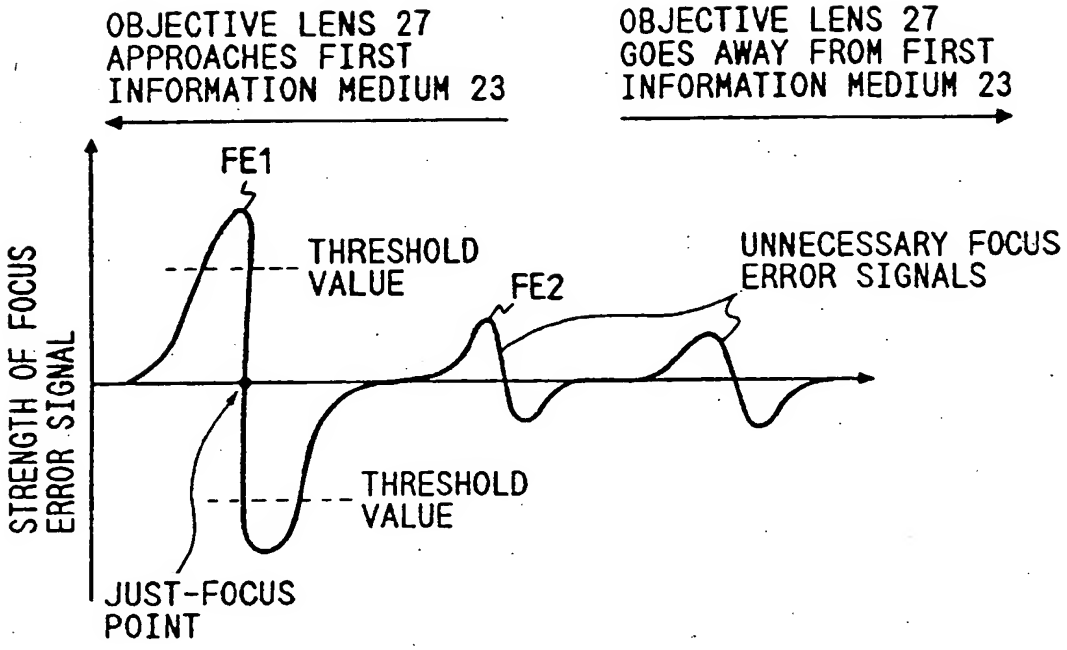

FIG. 35B

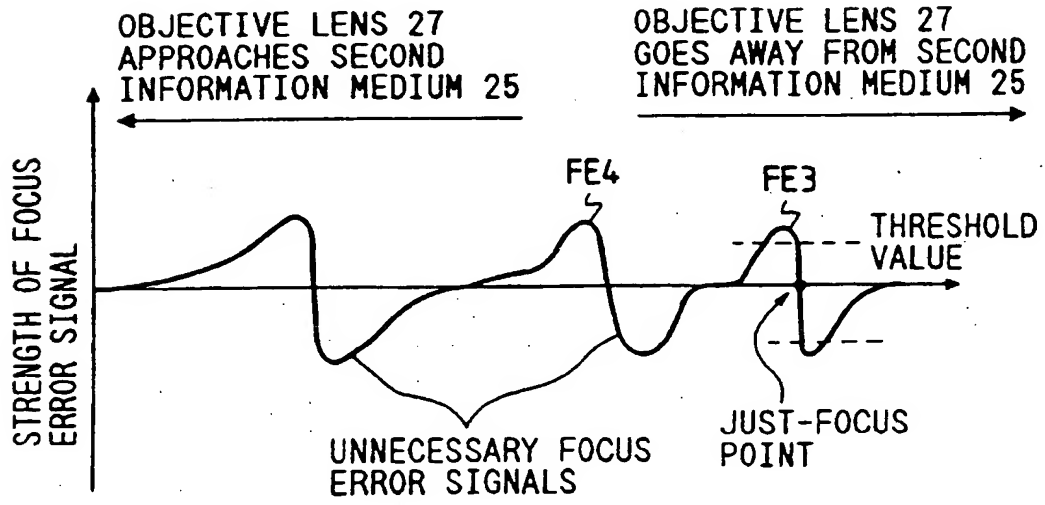

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FIG. 36A

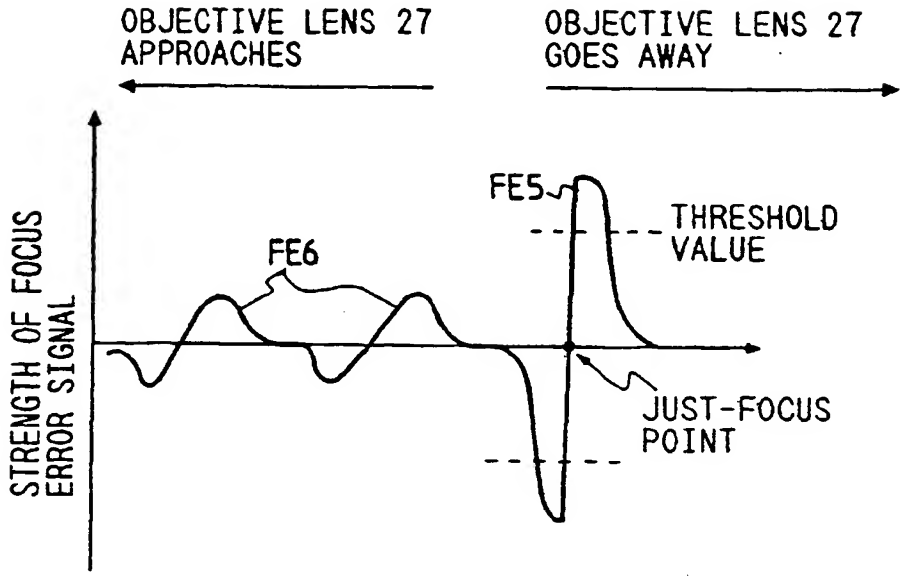

FIG. 36B

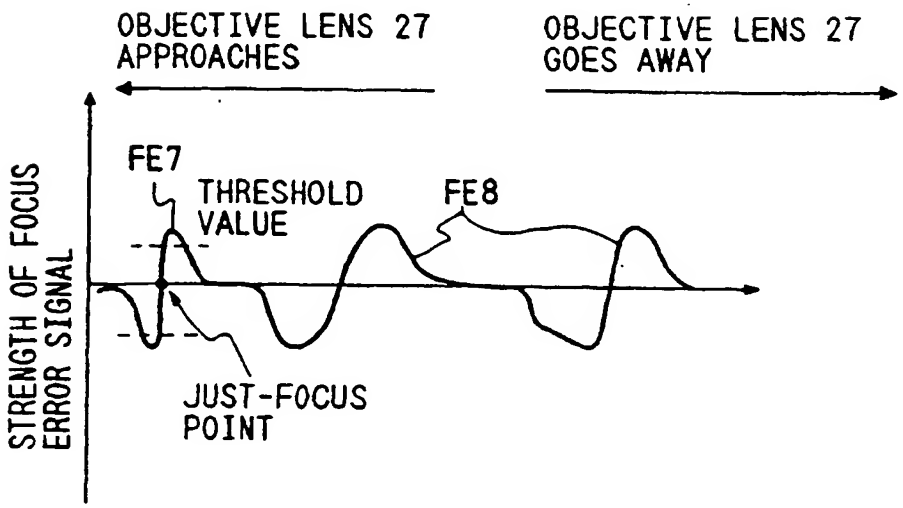

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FIG. 38

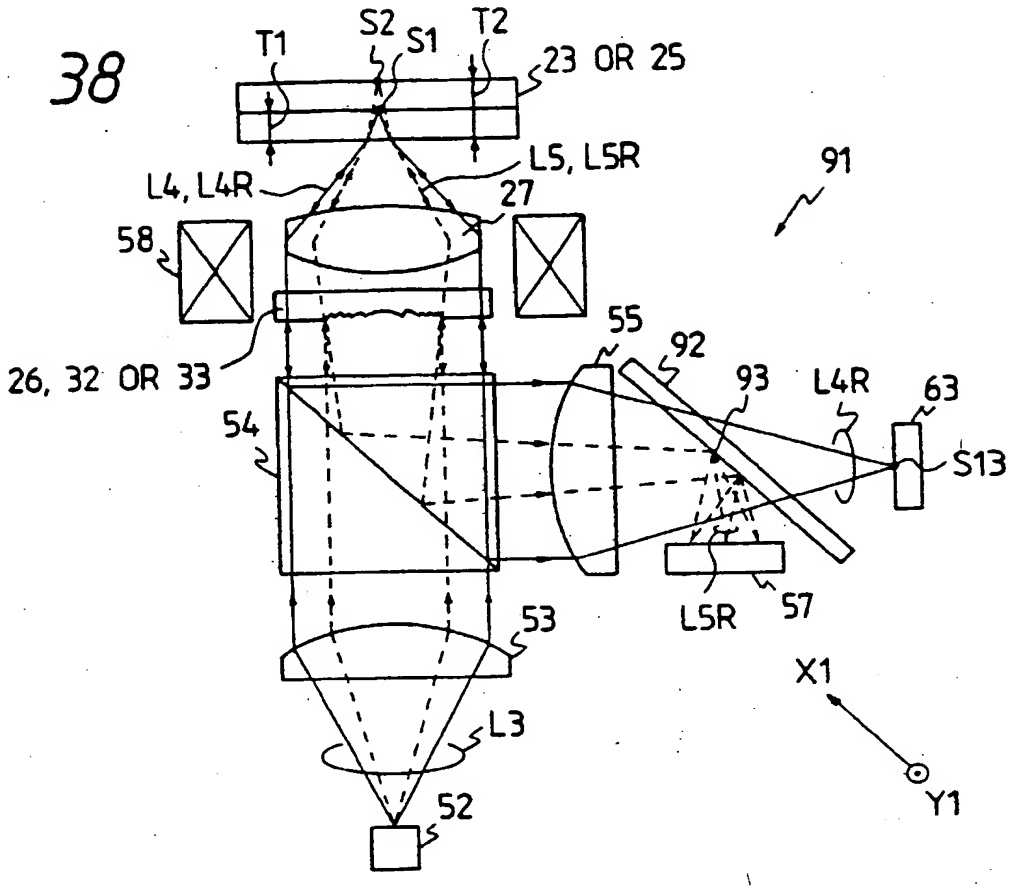

FIG. 39

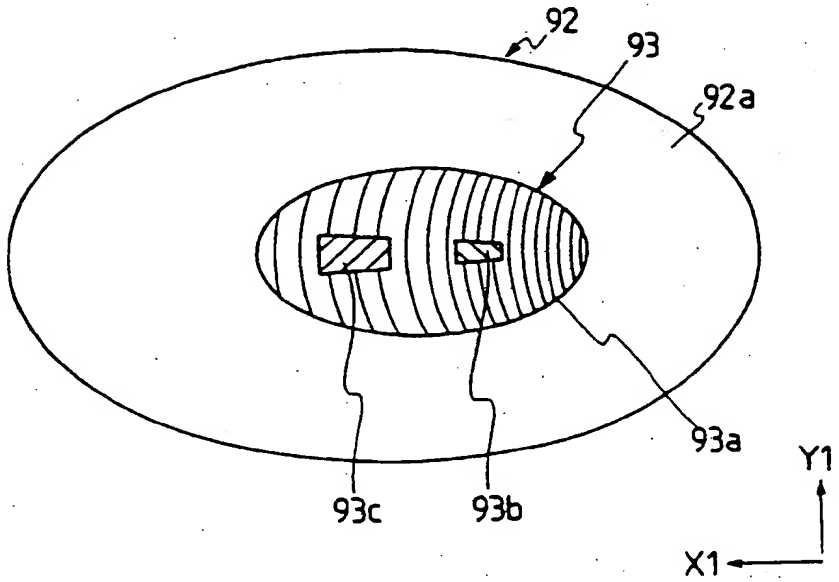

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FIG. 40A

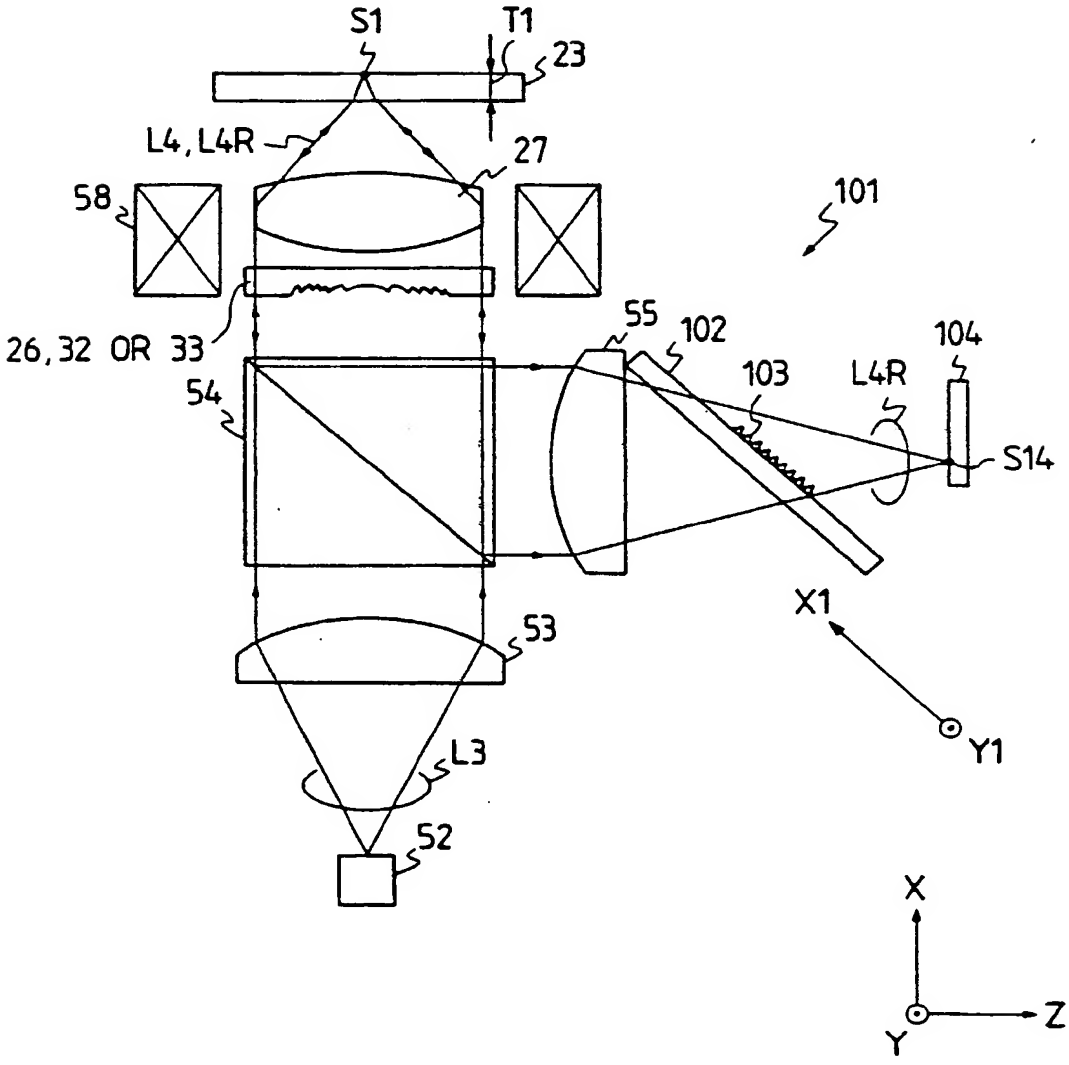

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FIG. 40B

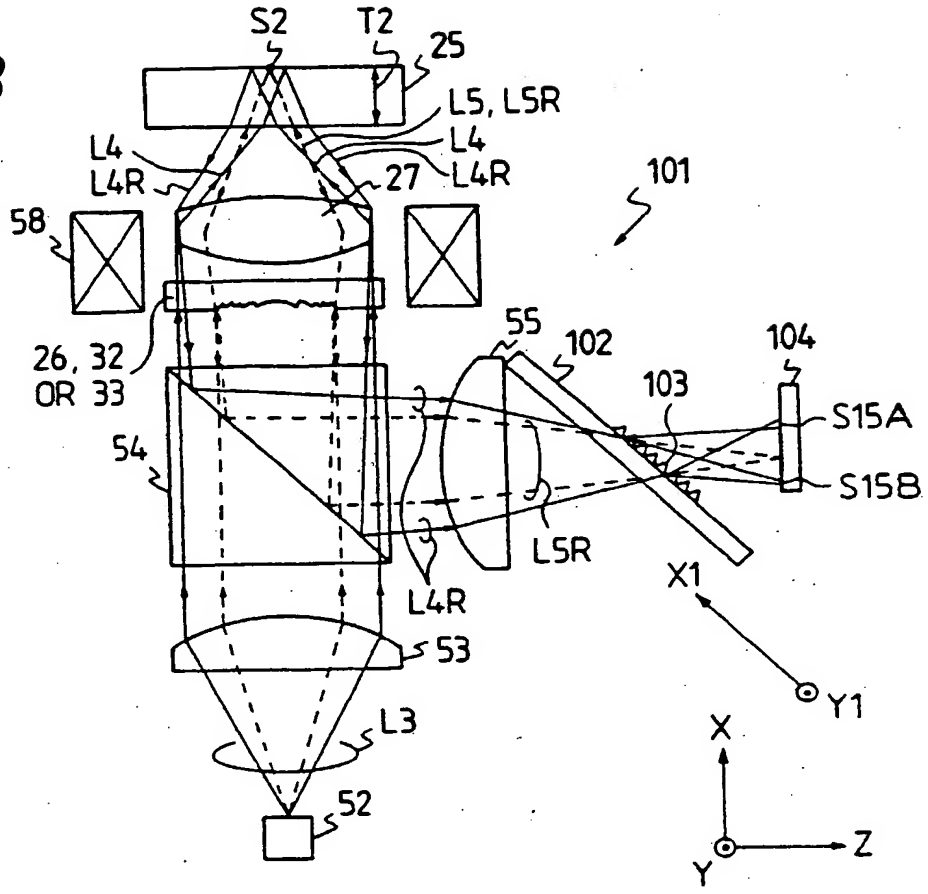

FIG. 41

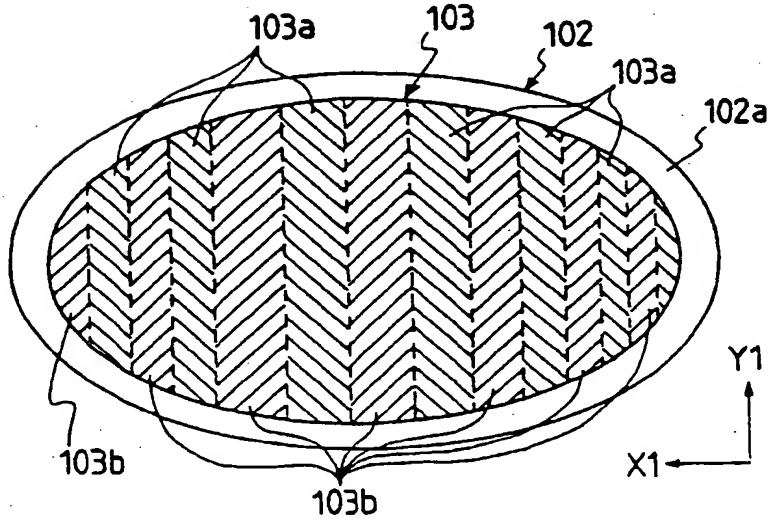

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FIG. 42A

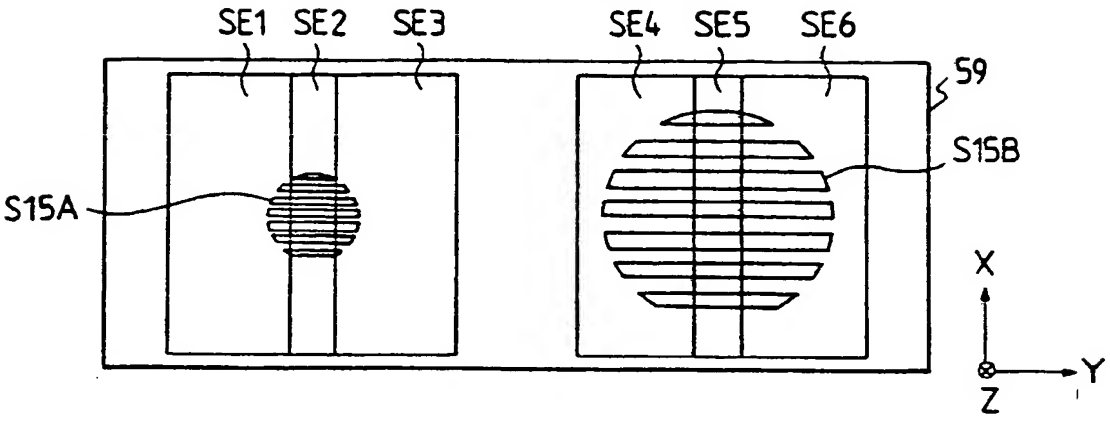

FIG. 42B

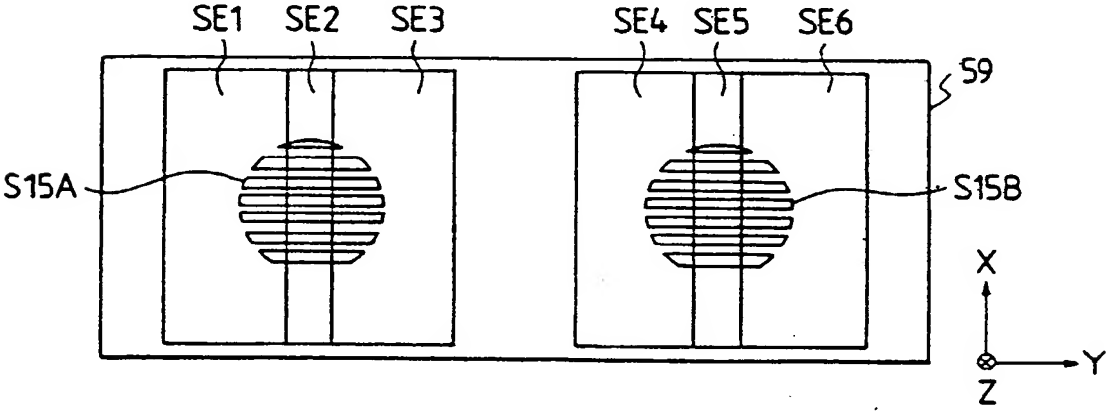

FIG. 42C

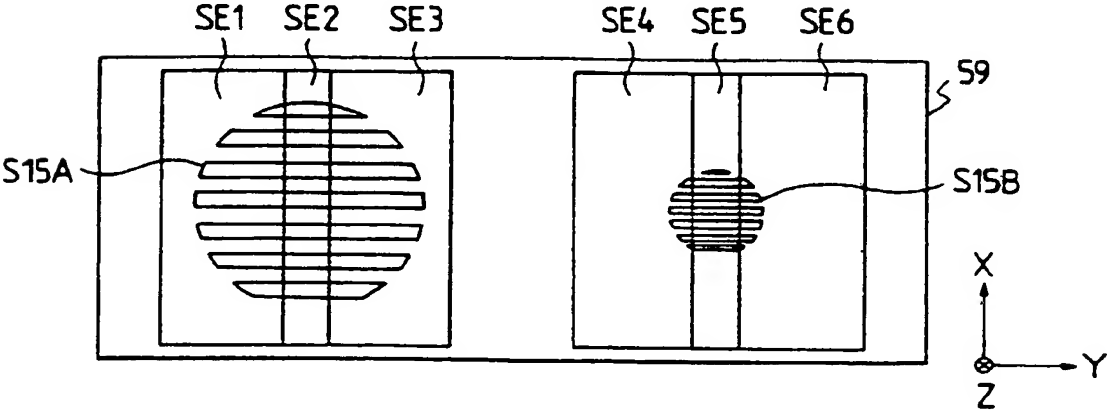

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FIG. 43

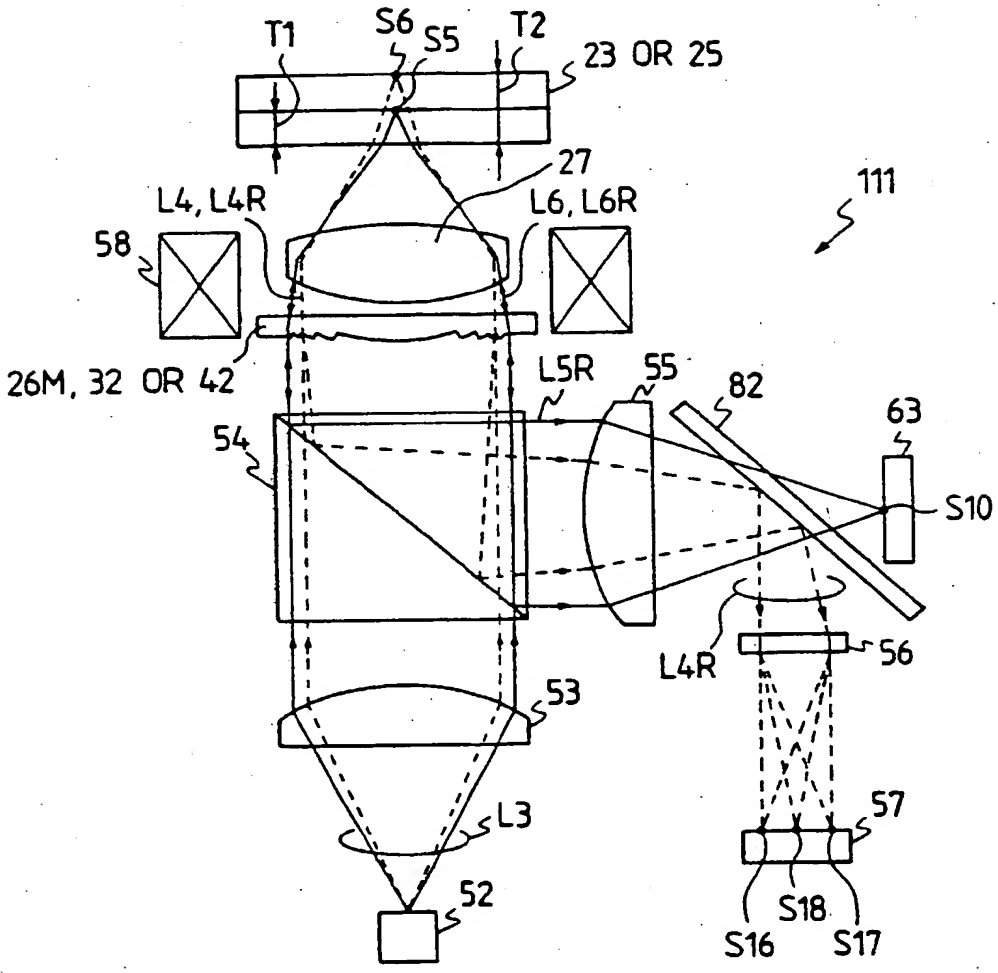

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FIG. 44

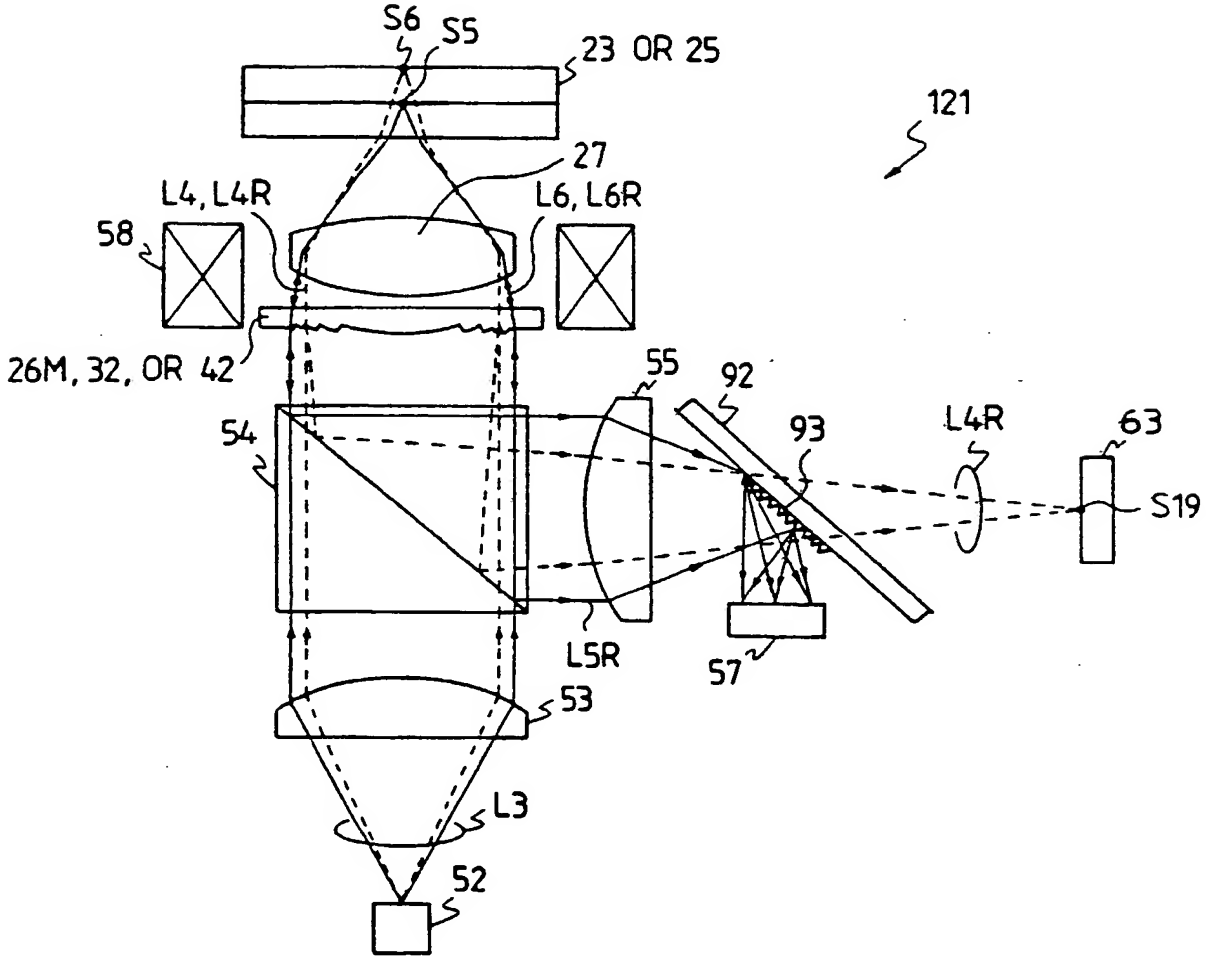

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FIG. 45

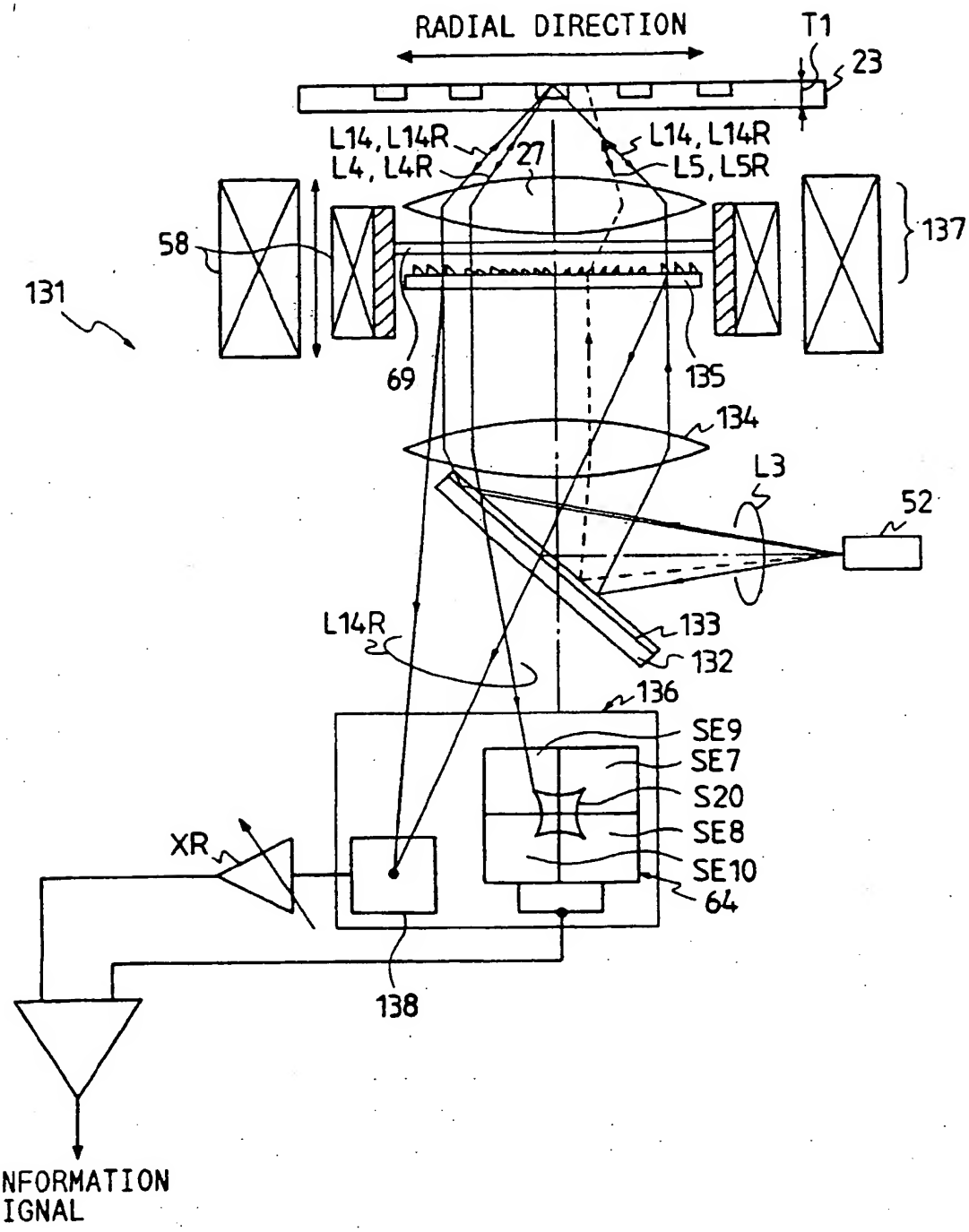

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FIG. 46

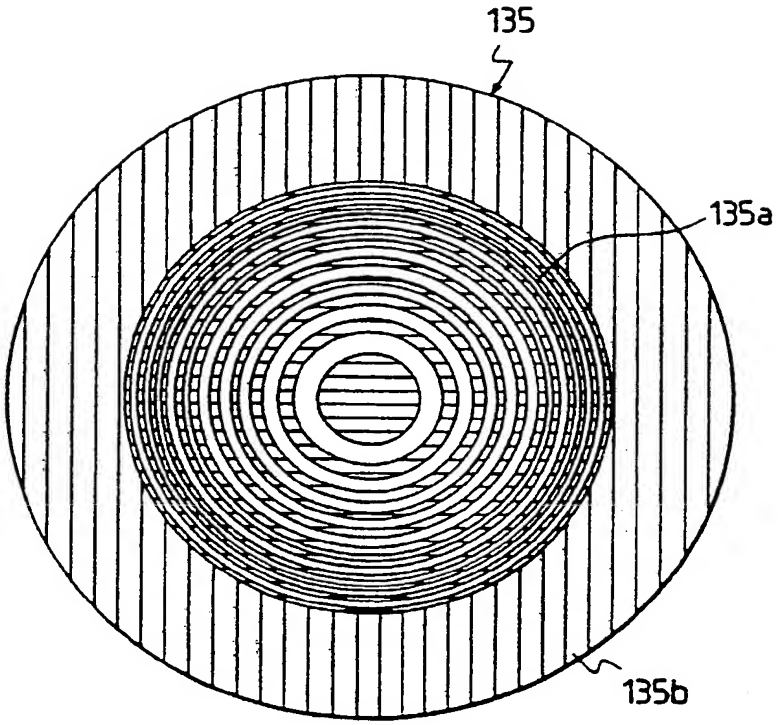

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FIG. 47

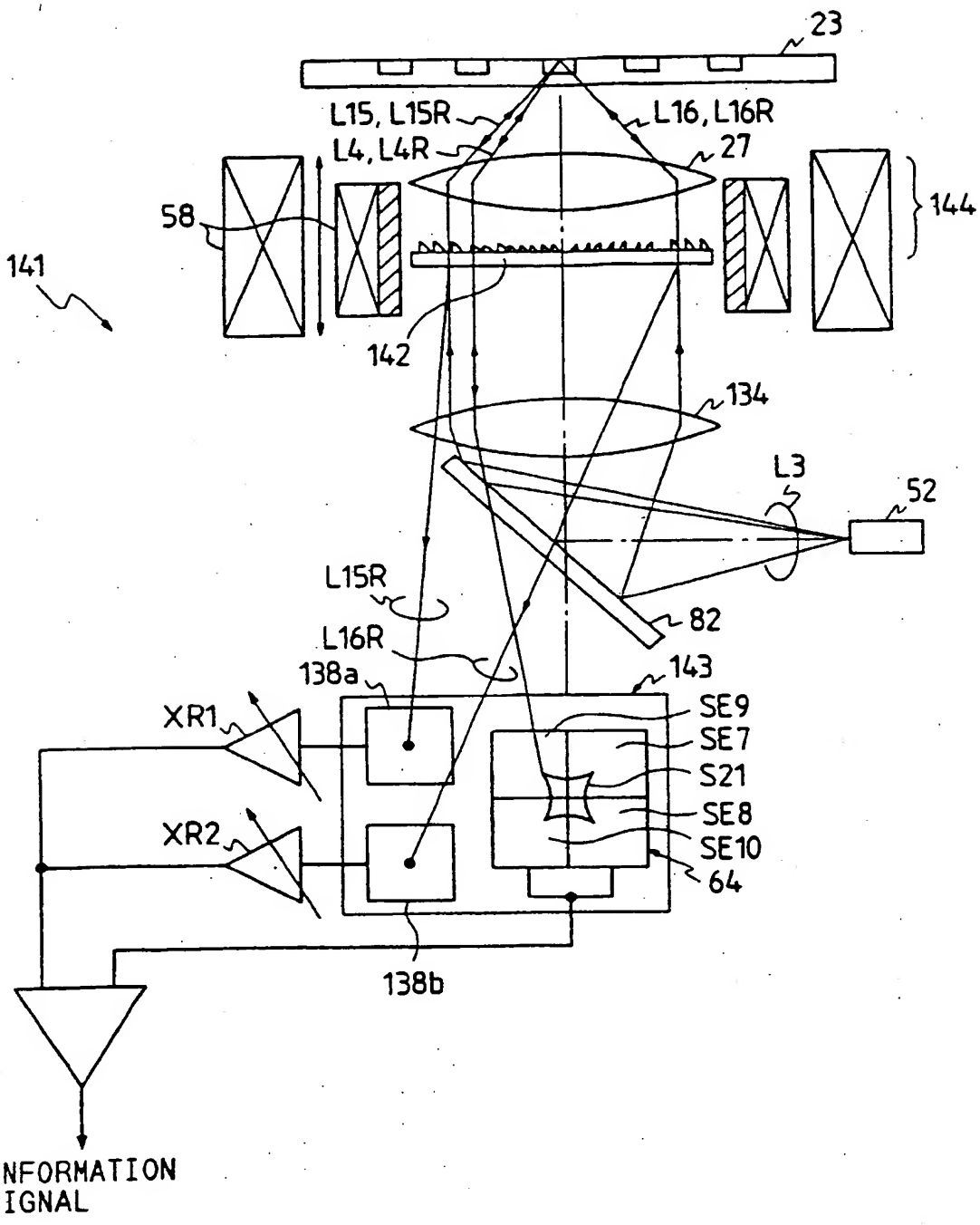

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FIG. 48

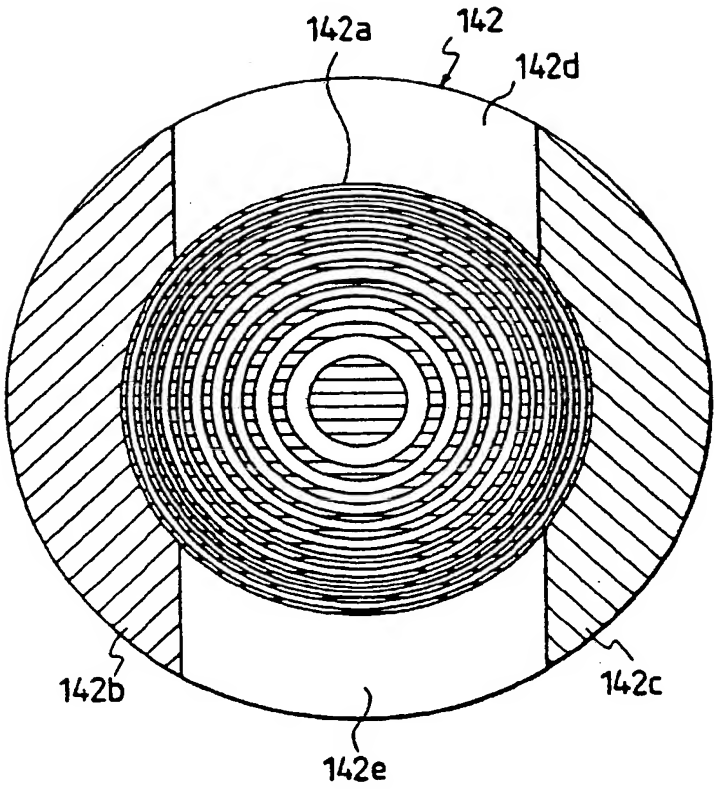

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FIG. 49A

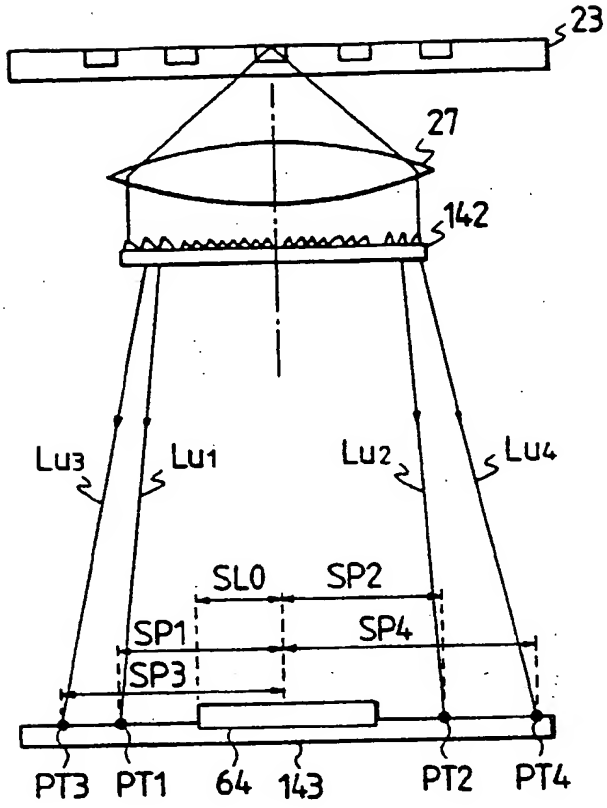

FIG. 49B

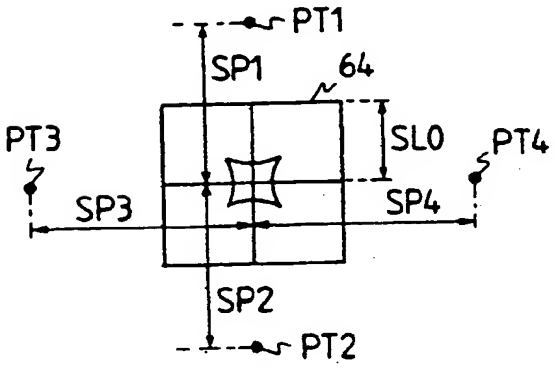

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FIG. 50

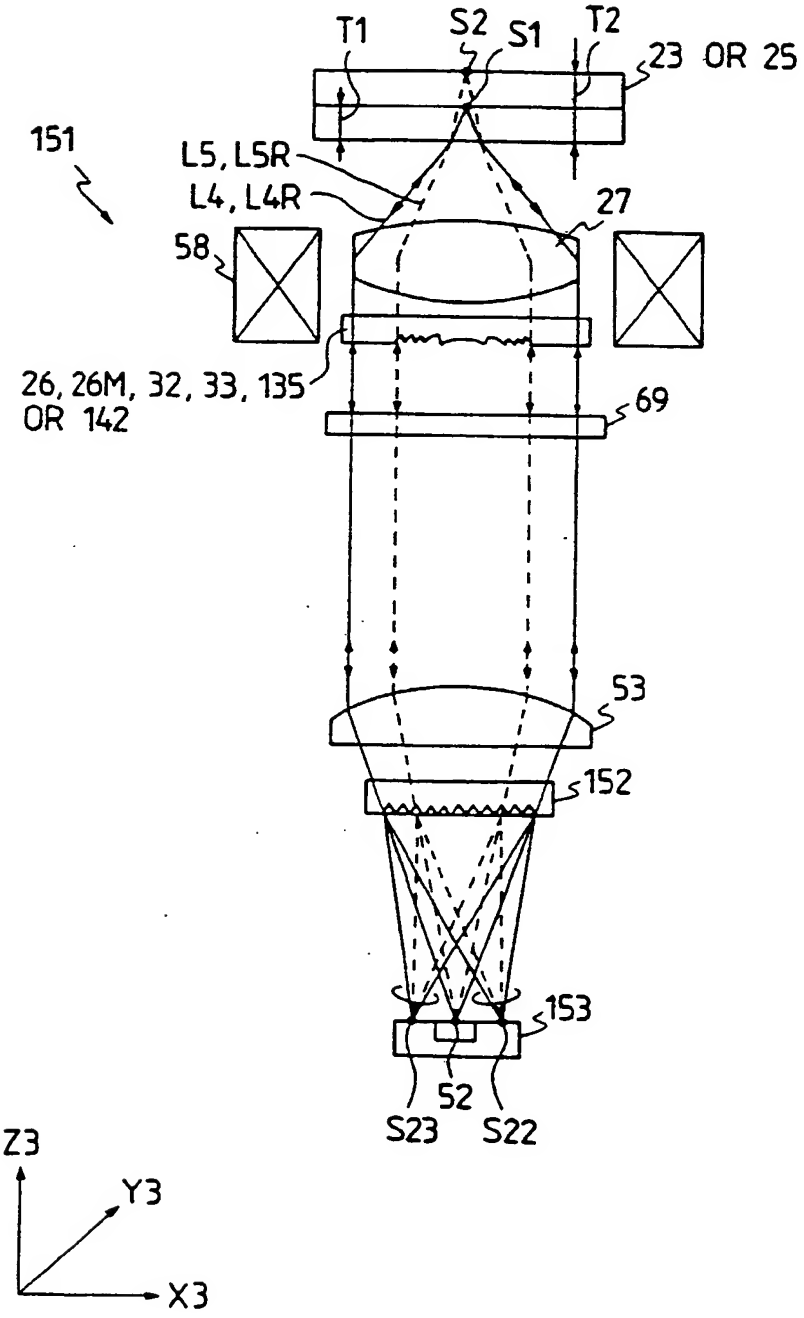

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FIG. 51

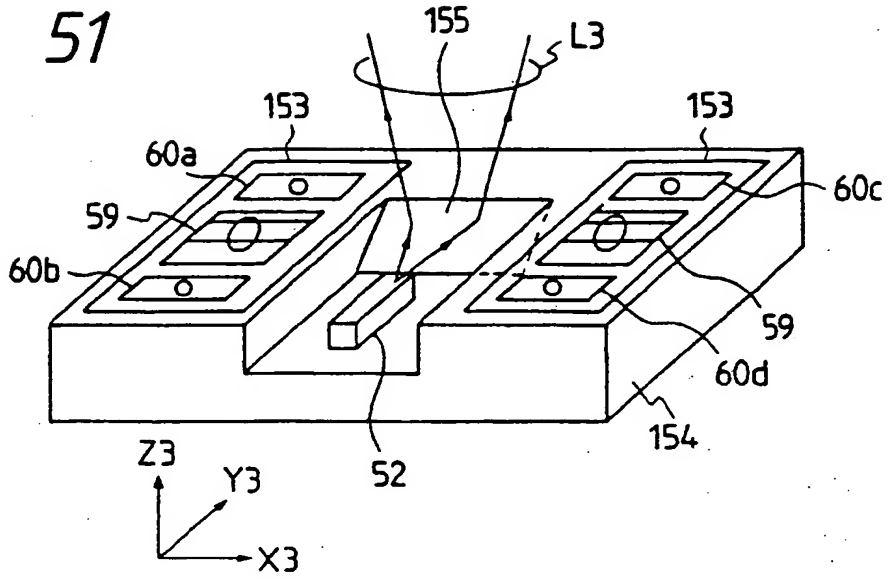

FIG. 52

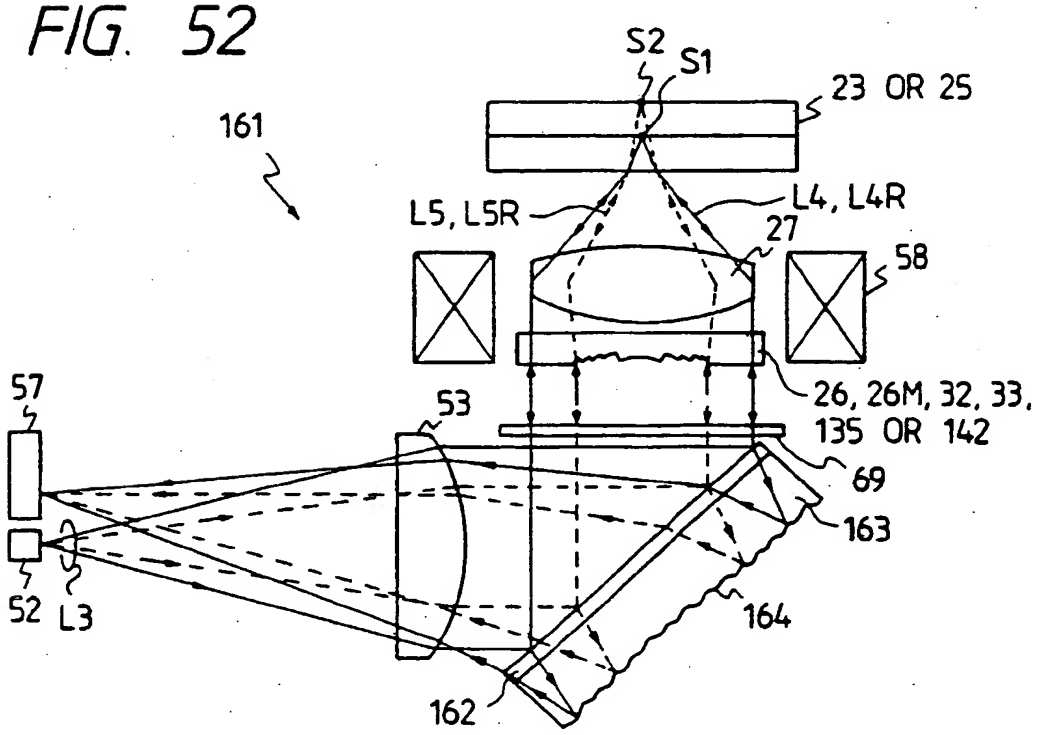

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FIG. 53

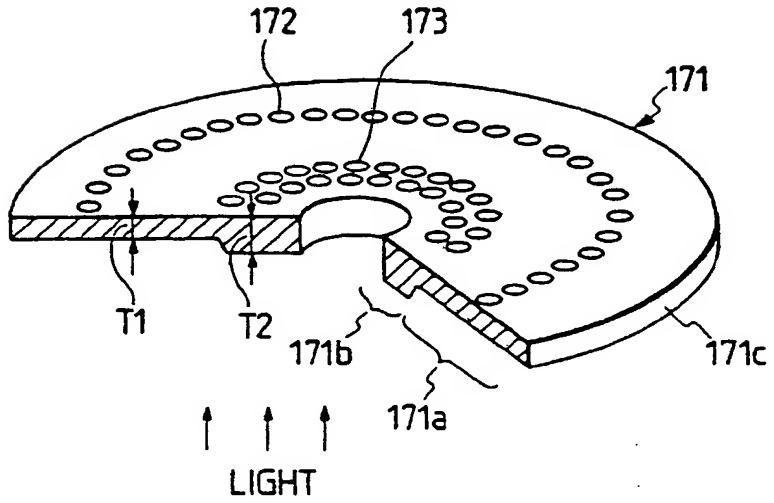

FIG. 54

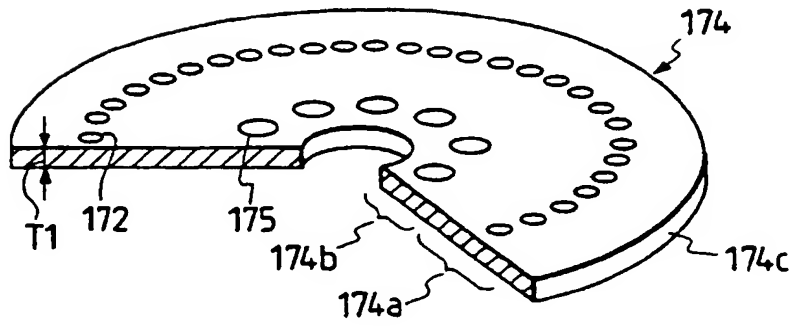

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FIG. 55

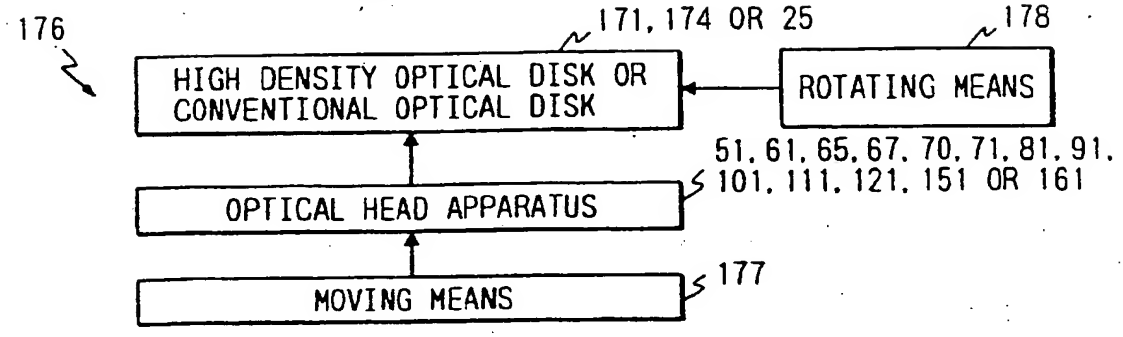
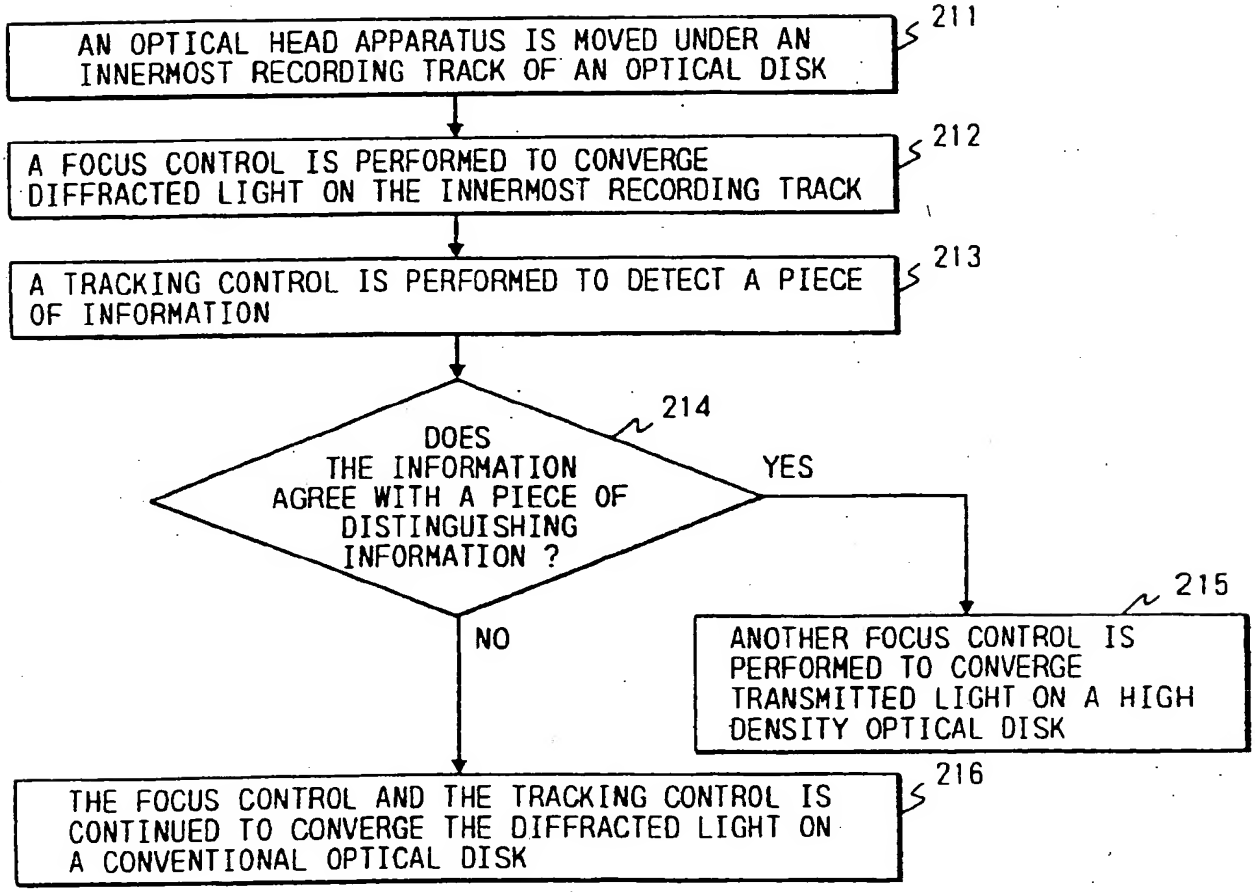


FIG. 56



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European Patent Office

EUROPEAN SEARCH REPORT

Application Number
EP 97 12 2035

DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (Int.Cl.6)
A	EP 0 452 953 A (MATSUSHITA ELECTRIC IND CO) * column 5, line 4 - line 7 * * column 7, line 8 - column 8, line 40; figure 2 *	1,2	G11B7/135 G11B7/24 G11B7/00 G02B21/02 G03F9/00 G02B5/18 G02B5/32 G11B7/007
P,A	PATENT ABSTRACTS OF JAPAN vol. 17, no. 457 (P-1597), 20 August 1993 & JP 05 101540 A (DAINIPPON INK & CHEM INC), 23 April 1993, * abstract *	1,2	
P,A	PATENT ABSTRACTS OF JAPAN vol. 018, no. 042 (P-1680), 21 January 1994 & JP 05 266491 A (BROTHER IND LTD), 15 October 1993, * abstract *	1,2	

TECHNICAL FIELDS SEARCHED (Int.Cl.6)

G02B
G11B
G03F

The present search report has been drawn up for all claims

Place of search	Date of completion of the search	Examiner
THE HAGUE	30 January 1998	Annibal, P

CATEGORY OF CITED DOCUMENTS

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